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ROAD FREIGHT LAB

Demonstrating the GHG reduction potential of asset sharing, asset optimization and other measures

Contents

Executive Summary

Transport accounts for 20% of global final energy consumption, and road-freight is a rapidly growing component of that, especially in developing countries. The WBCSD's Road Freight Lab initiative aims to investigate and select measures that companies can adopt to reduce GHG emissions from road freight transport. This report represents a mature stage in that process, discussing six high potential measures and attempting to quantify their benefits via data collection, modelling and other evidence. The key outcomes are:

- Use of top-tier asset optimization tools could reduce energy use and emissions by on average 12.5%, and are still to be taken up by approximately 85% of fleet operators;
- The increasing prevalence of tight delivery windows, especially in the 'last mile' context, is set to *increase* transport energy use and emissions if left unchecked; but relaxing delivery windows from 1hr to 5hrs could lead to savings of 25%;
- Modest asset sharing models that can save 15% of cost are only being used by 20% of operators, while highly integrated vehicle and depot sharing can lead to a 20% savings and is yet to be taken up in the case of at least 85% of commercial vehicle miles;
- Accelerated adoption of immediately available alternative fuels such as biogas and electric vehicles would lead to a 58% reduction in GHG emissions;
- Widespread adoption of vehicle-centric efficiency measures would lead to a 32% reduction in fuel consumption;
- Eco-driver training has been widely adopted in many markets and can save on average 7% GHG emissions by better fuel efficiency.

The solutions relating to alternative fuels and drivetrains, vehicle efficiency and driver training are well known and many local initiatives are in place to help deploy these across fleets. On the other hand, solutions relating to optimization, relaxing delivery time windows and asset sharing are either not known or the market does not yet offer ready commercial solutions to fleets.

The WBCSD will continue to facilitate collaboration between member companies and partners to better understand how these solutions can be developed into viable business models and deployed at scale across road freight transport providers. Given the scale of the necessary challenge to decarbonize transport, the WBCSD and its members recognize the need to develop all solutions. Those described within this report will all be key elements in the fight against climate change in the road freight sector.

1. Introduction

Transportation alone accounts for 20% of final energy consumption [IEA Energy Technology Perspectives, 2015], and the largest share of energy use within the transport sector comes from road vehicles [Sims et al./ IPCC AR5, 2014]. Energy use in the road-freight sector has dramatically increased since 1990 in both OECD and non-OECD countries.

The transport sector will significantly evolve by 2050. The global demand for road freight, measured in ton-kilometers, will almost triple between 2015 and 2050 [ITF, 2017], with the growth concentrating in developing economies. For example, non-OECD countries accounted for roughly 80% of total new roads built since 2000. By 2010, non-OECD countries averaged about 40% more travel (in total kilometers[1] travelled) than OECD countries on roughly 20% fewer infrastructure kilometers. With more travel on fewer roads, it seems likely that urban traffic congestion in non-OECD countries tends to be worse than that in OECD countries, and is likely to degrade further in China, India, the Middle East and Africa, where increasing demand continues to outpace roadway construction [IEA Energy Technology Perspectives, 2015].

Around a third of intra-EU long distance freight is by road transport [EC White Paper, 2011], and for distances <500km, road transport is the only economically viable solution; around 80% of road freight transport is for distances < 150km [ECR Europe, 2000].

Transport produces a quarter of the EU's greenhouse gas emissions, of which road transport contributes to over 70% [European Commission White Paper, 2011]. Consequently, accounting for 15%--20% of emissions.

The WBCSD is exploring a number of practical measures that could be promoted for global carbon footprint reduction in the freight sector. The practical measures suggested can be achieved by majority of operators at low or reasonable cost. Operators fall into two groups: (i) those relating to logistical arrangements, both in the contexts of individual operators, and the sharing of data and other assets between pairs or groups of operators; (ii) those relating to materials and human factors, such as fuels, vehicle modification, and driver training.

[1] Throughout this report we the metric system for the international context or where a location is not specified. In all other cases we use local units (e.g. miles in UK and USA).

For the first group, focus is given to the potential benefits that would arise as a result of the following three measures:

a) Use of top-tier tools for optimizing routing and resource-allocation;
b) Changing the business context to avoid narrow delivery windows;
c) Promoting the sharing of assets (vehicles and/or depots) between suitable groups of operators.

In each case, the report surveys and summarizes associated literature, moreover reporting novel research and evidence regarding freight transport.

With reference to materials and human factors the report considers the following measures:

a) 'eco'-oriented driver training;
b) alternative fuels;
c) vehicle-centric efficiencies, via modifications to on-board components or systems.

In each case a high order summary of recent associated literature and other resources is provided.

By review of available material, and in some cases enhancing that with new research and evidence, our purpose is to offer the following for each of these six measures

1. Indication of the general potential for carbon footprint reduction (based on a combination of modelling and available data);
2. quantified estimates concerning the global significance (based on a variety of assumptions and facts drawn from a wide variety of sources)

In the remainder, we consider these measures in turn, in each case ending with 'key messages' which are summarized again at the end of the report.

2. Benefits of High-Quality Routing and resource/allocation

2.1 Introduction

Road transport routing and scheduling involves meeting the following conflicting objectives [Emmet, 2009]:

- Maximizing vehicle driver's time
- Maximizing the vehicles' carrying capacity (weight and/or cube)
- Minimizing the distance travelled
- Minimizing the fleet size
- While satisfying cost and service parameters.

The relative importance of these objectives may vary between organizations and depend on the problem at hand. Each organization requires a routing and scheduling plan that is specifically tailored to their prioritized objectives. This granular capability will ensure efficient utilization of available transport capacity in a way which minimizes environmental impact by considering a wide range of problem-specific factors and associated data. Each scenario relates to the characteristics of (a) the customer demands to be met, (b) the resources available to meet that demand, and (c) the transportation network over which those resources will operate.

Presently, many organizations manually perform the aforementioned task even though many software vendors claim Computerised Vehicle Routing and Scheduling (CVRS) can bring significant benefits, with typical cost savings of between 5%-30% [Hosny, 2014] in comparison to manual processes. It is natural to believe that greater benefits are available in cases where the scale of the operations is very large or its details are very complex or dynamic. However similar benefits may be available to smaller operators, since the solutions found via CVRS to achieve ideal balances among the objectives are often counter-intuitive, with considerable improvement over the manual schedules that would be typically used in smaller operations.

A best practice guide was formulated by synthesizing findings from a 2004 survey of 700 members of the UK Freight Transport Association whom operated 10 or more vehicles. Among the few members who reported use of CVRS, 75% experienced improved efficiency, 58% reduced operating costs, 38% decreased fuel costs, 29% reduced their fleet size and 29% reduced total mileage. Over half of CVRS users reported a 58% improvement in wider business benefits including improved management reports and displayed a 54% enhancement in customer service.

2.2 Evidence from modelling

Benefits delivered by top-tier route optimization tools are assessed by comparing optimized to 'regular practice' solutions. The performance of benchmarking exercises between clients' historical operations and route optimization using a CVRS provider's solutions made this comparison possible. Owing to the fact that historical transport operations data is rarely retained in a company, the possibility to carry out a comparison is actually quite rare. Presently, Route Monkey Ltd (RM), a member of the WBCSD Road Freight Lab Working Group, has contributed the necessary data from 35 fleets. Data for each fleet includes both a benchmark plan – reflecting what would have been done without high-quality optimization in use – and an optimized plan.

The 35 fleets from which these data were gathered ranged in size from 5 to 52 vehicles, with each fleet covering on average 105,000 miles per year. Their sectors included recycling, furniture, foods, removals, waste collection, fuel transport, parcel delivery, pharmaceutical supplies, healthcare, and commercial cleaning. Figure 1 summarizes the overall results, contrasting percent savings in optimized mileage against fleet size.

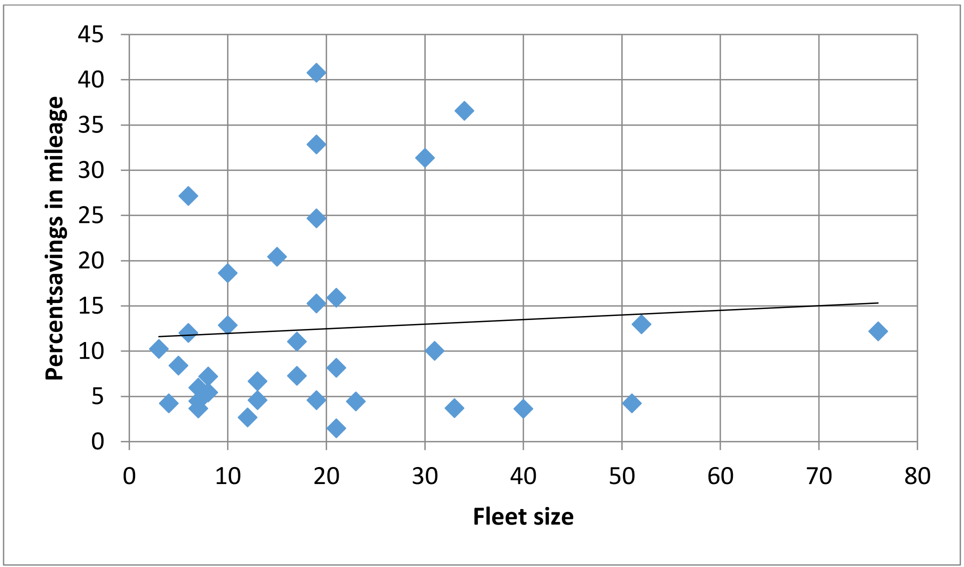

Figure 1: Optimized mileage against fleet size for benchmark fleets

Figure 1 reveals immense variation between fleets, and we have been unable to determine a pattern that relates improvement to sector or fleet size; the plot suggests a correlation between improvement and fleet size, but the correlation is very weak.

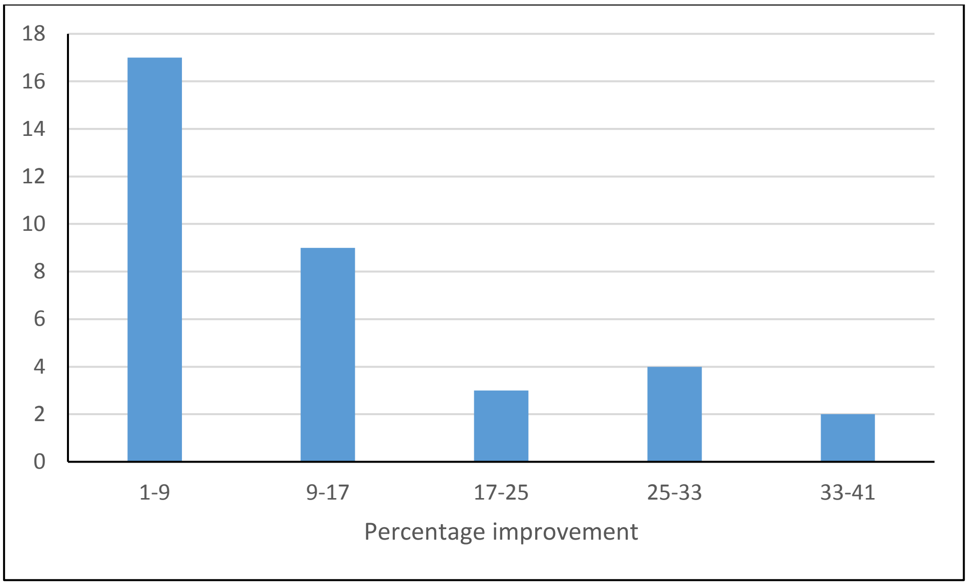

Figure 2: Distribution of percent savings in total mileage to benchmark fleets (histogram generated using easycalculation.com)

Summary statistics are visualized in figure 2, which shows roughly half of the fleets showing improvements of 1 to 9%, while the remaining Centre at around 9—17%. The detailed range and summary statistics are as follows:

Table 1: summary statistics from fleet benchmarking exercise

Range of improvement among the 35 fleets	1.5% to 40.8%
Mean improvement	12.5%
95% confidence range around the mean	9.0% -- 16%

The confidence range on the mean emerges from standard statistical assumptions which (as must always be said) may not be true in practice, such as having used a statistically unbiased sample, and the population of potential improvements being normally distributed. Nevertheless, the percentage improvement values emerging from this exercise are consistent with other findings (as we indicate below), and underpin a solid expectation that 12.5% improvement in mileage (and hence also GHG emissions) would be a reasonable expectation for an average fleet.

2.3 Further associated evidence

Characterizing the benefits associated with route optimization relies on availability of pre-and post-optimized data and as a result are challenging to formulate. Companies involved in transportation have been found to rarely keep their former (pre-optimized) route schedules and plans that could assist in future benchmarking studies. Former research has focused on comparing different optimization methods with each other, but neglects to account for the benefits between using machine optimized versus manual optimization route planning methods. Nevertheless, the following third-party evidence was found.

The Department for Transport in the United Kingdom issued a best practice guide in 2007, that aimed at helping organizations better understand CVRS (Commercial Vehicle Route Scheduling) and move towards its use. The more complex the route plan (involving large volumes of data) under short time restrictions results in customers reaping the largest benefits in terms of time, cost and emissions savings. An example would be if a scenario involving fluctuating demands and multi-drops with 10 or more vehicles. The integration of the CVRS software with other broader supply chain management software will allow for the realization of these benefits. The research thus far implies a typical transport cost saving of 10-20%, supporting the business case for this complex integration of software. Hosny's [2014] research supports this finding by reporting software vendors claim a typical cost saving of 5%-30% in comparison to manually planning their travel routes

In summation, direct evidence gathered from the 35 fleets analyzed is consistent the associated evidence within literature. In particular, the calculated mean of 12.5 ±6% represents a conservative yet realistic estimate of the benefits customers could expect from transitioning to automated fleet route optimization.

2.4 Wider implications

To understand the wider implications of the findings above, we need a broad idea of the degree to which existing fleet operations are already optimized. Received wisdom is that this figure is increasing as computers become more affordable and demand for cost-savings become more urgent; however, it is increasing from a relatively low baseline, since many operators (especially smaller ones) are content with pragmatic manual planning, and are unconvinced that route optimization tools merit the costs of their deployment.

For example, Simchi-Levi et al (2005) noted a variety of pragmatic approaches being used to address logistics problems in practice. These included repeating what was done in the past, applying "rules of thumb" and applying practices used by competitors. Meanwhile, the identification, introduction and operation of a CVRS which is well suited to an organization's specific needs can often require investment in time and effort as well as cost, which can create a barrier to successful implementation. Despite CVRS having been available for over a quarter of a century, such existing practices and cost barriers underpin its relatively slow uptake.

The UK published a best practice guide that was formulated based on a 2004 survey of 700 members of the UK Freight Transport Association whom operated 10 or more vehicles with similar fleet profiles. CVRS was reported to be used by 15% of the members with an additional 7% susceptible to transitioning to CVRS (UK Dept. of Transport, 2007). This left 78% of the members reliant on manual or similar approaches.

Based on the UK's 'Continuing Survey of Road Goods Transport, Greening et al [2015] reported an annual uptake of 1.2% in fleet management software since 2009, and stood at 11% of the HGV freight sector in 2010. This presently corresponds to approximately 18% take-up in the HGV sector.

Considering the available evidence on take-up, and noting that the adoption of fleet management software does not necessarily correspond to its use for frequent route/asset optimization, the WBCSD can tentatively conclude that 85% of the transport market is still yet to transition to use of high-quality route optimization. This conclusion comes after consideration of available evidence on take-up, and noting that the adoption of fleet management software does not necessarily correspond to its use for frequent route/asset optimization. Consequently, full take-up in the UK alone, where commercial vehicles account for 60 billion vehicle miles, could therefore save 6.4 billion vehicle miles could be saved per year.

2.5 Key Messages

Asset/route optimization with modern fleet software can save on average 12.5% of a fleet's transportation costs. Research outcomes found cost savings of individual cases varying between 3% to 40%, but the broad average of 12.5% emerged from the modelling done in this report, and is consistent with other studies and anecdotal evidence.

Assessment of a number of indirect sources suggests that current levels of take-up of modern fleet routing software is relatively low, though rising. Based on the available evidence, we estimate that the current level of take-up is 15%. Consequently, we therefore estimate that around 85% of the road freight sector operates routes that are essentially un-optimized.

3. Benefits of widened delivery windows

3.1 Introduction

A commercial vehicle fleet is tasked with making several deliveries across a reasonably wide region. Each of these deliveries is invariably subject to a time window (e.g. 09:00—11:00), which represents the recipient's availability and/or preference for receipt of the delivery. A wide variety of scenarios occur in practice with regard to the significance of the time window. Two extremes are characterized below:

- Hard/narrow: delivery in the window is a hard constraint, and the time window itself is quite narrow (maybe 1 hour or even less); financial and other penalties will be incurred if the delivery is not made on time;
- Soft/wide: delivery in the window is preferred, but not essential, and the time window is wide (perhaps the entire working day).

The consideration of time windows in this report stems from two facts. First, scenarios of the 'hard/narrow' type are becoming increasingly prevalent, fueled by growth in e-commerce and associated shifts in customer expectations. Second, however, the 'hard/narrow' scenario has significant negative implications for mileage and GHG emissions. As a result, the effects of time windows on emissions and route optimization was included in the WBCSD-led modelling effort to provide potential evidence for legislation or other mechanisms to dissuade operators and clients from the 'hard/narrow' scenario. As discussed later, there are reasons why this might not be welcomed, especially on the customer side, but there are nevertheless strong reasons from the operator side and emissions mitigation benefits.

3.2 Evidence from modelling

Operational data was obtained from 20 UK fleets. In each case the data comprised a single day's delivery requirements. For each of these 20 cases, 100 separate route optimizations were performed. Ten optimizations were performed per time window which ranged from 1 -10 hours in 1 hour intervals. The windows were always uniformly distributed across deliveries between 08:00 and 18:00. For example, in the '8-hour' experiments, each customer was assigned a window at random, which was equally likely to be one of the following: 08:00—16:00, 09:00—17:00, 10:00—18:00. In this way, for each of these cases we collected a spread of results from 10 window sizes.

Figure 3 shows the results of the aforementioned experiments, performed with a single fleet's data. The outcomes showed only very moderate change in cost to mileage incurred moving from 10-hour to 5-hour windows. In terms of route optimization, this result is due to the many combinations of route options that can achieve the same overall result. For example, in the case of a 10-hour delivery window an optimized plan may involve a single vehicle traveling as follows:

Depot → A → B → C → D → Depot

When the delivery window is reduced to 5-hours, to meet time constraints, the original route could still suffice or may need to change to:

Depot → D → C → B → A → Depot

This route change may have no effect on mileage. However, windows shorter than 5 hours for each delivery limit possibilities for this style of low-cost rearrangement, as the route is tightly constrained and incur unavoidable costs in mileage.

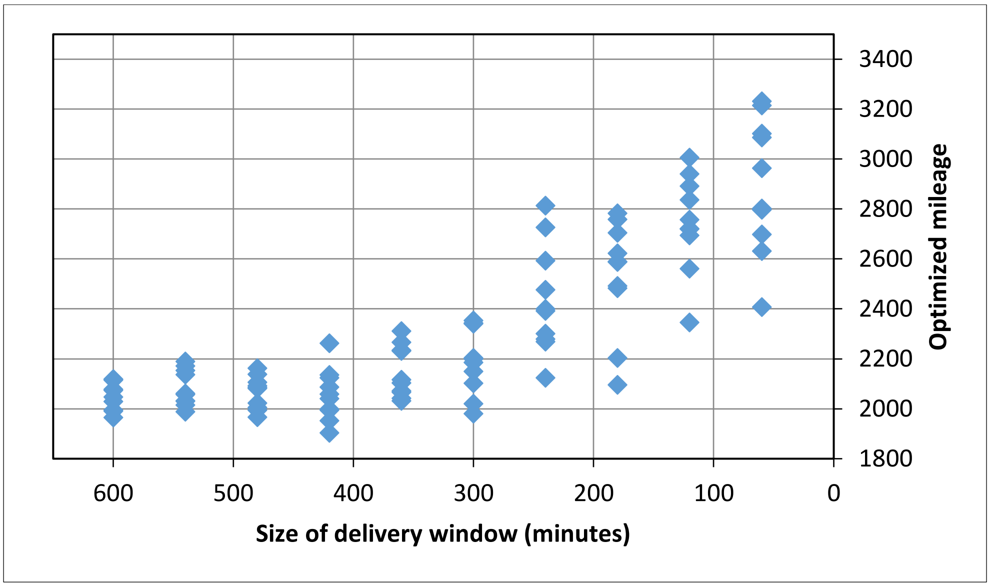

Figure 3: Mileage optimized for ten independent experiments of a single fleet for varying delivery window sizes

The mean percentage improvement in mileage covered as delivery time windows are relaxed from 1 -10 hours is summarized in Figure 4. Mileage travelled for a set of deliveries is minimized by 6%

per hour when as the delivery window relaxes up to 5 hours. Overall, relaxing the delivery window from 1 hour to half a working day saves 25% of the mileage that would have been covered.

Figure 4: Median percentage improvement in mileage (over 10-hour window) against delivery window size across all experiments

Statistics summarizing the results obtained from performing the delivery window experiments can be seen in Table 2.

Table 2: summary statistics from window relaxation experiments

Mean improvement per hour relaxed (1 to 5 hrs.)	6.2%
Mean improvement from 1hr to half day	24.8%
95% confidence range around the per-hour mean	3.9%--8.5%
95% confidence range around the per-hour mean	20.1% -- 28.9%

3.3 Further associated evidence

Very few studies have directly investigated the effects of delivery windows on mileage. Though increasingly understood by operators to affect costs and complicate routing, investigations surrounding delivery-slot offering and pricing strategies – particularly in the light of the e-commerce boom – has taken precedence over the environmental implication of tight delivery windows on mileage with transport operators. Nevertheless, two studies provide associated evidence.

Boyer (2009) investigated the relationship between delivery window length, customer density, and miles per customer, in the context of the three main US delivery scenarios: urban (~30% of US households), suburban (~40%), and rural (~30%). Extensive simulations were run for delivery window-sizes that ranged from 1 -9 hours. It was found that, on average, relaxing from a 3-hour to a 9-hour delivery window led to a 15% mileage saving, while relaxing from 2-hours to 3-hours led to a 7% mileage savings (Boyer, 2009). Customer density was found to have a significant impact, with a 10% variance experienced between rural and urban areas when changing from a 3 to 9-hour delivery window (Boyer, 2009). Punakivi (2001) focused on the concept of 'umnanned' grocery delivery (where deliveries can be made to a reception box in the customer's yard). Results showed this delivery option to reduce transportation cost by 35% when moving from 1 to 2-hour delivery slots. This outcome is reaffirmed by results for high-density urban customers found in Boyer (2009).

The aforementioned research is broadly consistent with the savings calculated in this report. The severe 1 to 2hour effect in Punakivi (2001) seems extreme, however their simulation settings were consistent with high-density urban customers, and so this result is consistent with Boyer's findings. Overall, the suggestion is that our figure of 6.2% per hour-window-relaxation is conservative, yet indicative.

Another possibility to modify delivery time windows is exhibited by a case study from Nestlé (2012). Nestlé UK & Ireland's supply chain initiative 'Project Clockwork' was launched in response to customer desire to deliver unconstrained to a set daily pattern. Working to this principle and combining orders from a single geographic cluster across customers, Nestlé has been able to optimize vehicle utilization and cut costs while delivering significant inventory reduction to customers. This optimization of delivery windows allows a "milk run" delivery pattern as opposed to consecutive out-and-back deliveries to each customer. However, this arrangement required a manual intervention and negotiation rather than a dynamic ICT enabled delivery plan.

3.4 Wider implications

Previous research has failed to aggregate data to accurately infer on the wider implications of relaxed delivery windows on mileage saved. Route Monkey Ltd has been able to provide the lacking core data on distribution of delivery windows pertinent to this report. Scheduling constraints from a sample of 50 randomly selected UK Route Monkey clients over a range of sectors, were obtained and analyzed.

The distribution of customers using different delivery windows was as follows:

≤2 hours: 18%

2 ≤4 hours: 22%

4 ≤8 hours: 20%

≥8 hours: 40%

The sample from which these data were gathered represents a wide range of sectors, and, apart from all being UK fleets that have sought optimization services, is otherwise unbiased. Nevertheless, it is too small a sample from the full variety of extant sectors and delivery scenarios to invest much confidence in the numbers. Moving forward, the accuracy of the resulting distribution should be verified by gathering further data and performing additional analysis across a wider distribution of sectors and delivery scenarios.

Presently, there is extensive evidence available relating to how the current delivery/window distribution is slated to change in the short and medium term. This comes from the rising tide of online commerce and delivery services associated with the 'last mile', leading to steady growth in the frequency of narrow windows. WBCSD company experiences show that customers are more frequently paying extra for an assured delivery slot.

A survey of 3000 e-commerce customers in the EU found customers are increasingly considering the delivery experience when making purchase decisions [Metapack 2015] hence driving tight delivery window demand. Fast delivery has been found to be valued by 86% of customers followed by 80% prioritizing time slots, of which 49% paid additional fees for their preferred option. Further, 66% of customers had chosen one retailer over another based on their delivery options while half had abandoned an online order because of unsatisfactory delivery options. Meanwhile, the e-commerce logistics market is expected to grow at almost 10% annually from 2016 to 2020 [Technavio, 2016]. This growth is primarily due to growth in the cross-border e-commerce market, which is expected to increase at a rate of over 28% worldwide but particularly in emerging markets such as China. In the UK alone, more than three quarters (76%) of UK adults reported buying goods or services over the internet in the last 12 months, up from 53% in 2008 [ONS, 2015]. "Within the logistics industry, it is clear that the winners in this growing market will be those that can add value to the retailer by offering flexibility of delivery, state-of-the-art technology and efficient return services" [Barclays last mile report, 2014]. The report also indicates that 92% of logistics companies see e-commerce as the biggest growth area, and 45% of customers would order more online if delivery services were improved. According to figures in the Accenture 2014 global consumer research survey, suppliers are currently behind customer demand in this area. For example, globally, 41% of consumers want same day delivery while only 14% of retailers have same day delivery capability; also, while 75% of customers would value convenient scheduling, only 34% of retailers allow customers to schedule delivery and pick a timeslot. Emerging markets pose a greater challenge. In China, 55% of customers expect swift same-day delivery from online orders (Accenture, 2014) and “customers have high expectations for product delivery and little tolerance for failure” (Colliers and Bienstock, 2006). Perception of quality is also affected by the delivery service, for example, Colliers and Bienstock (2006) claim that product delivery is the most important factor affecting customers’ perceptions of quality and satisfaction with online purchases, and has the strongest influence on future purchase intentions; often perceiving delivery as high quality if it arrives early.

These customer behaviors challenge logistics operators who wish to avoid the need to offer narrow/hard delivery windows, and also challenges legislative frameworks or other mechanisms to change the direction of this trend. However, the costs and complications for operators are multiple and quite severe. First, the last mile can be a particularly expensive, inefficient and polluting part of the supply chain, due to high levels of failed deliveries and empty running [Gevaers et al 2011]. Contributing factors include the not-at-home problem in cases where a signature is required, reduced routing efficiency in cases of pre-arranged time windows, and lack of critical mass for efficient routing in cases of low customer density. The 2015 Accenture report suggests that absent customers is seen as an even bigger issue than cost management. E-commerce also leads directly to additional mileage via item-returns, since customers use the convenience of online ordering and return services to trial items, rather than take the time to choose in-store. Further, Boyer (2009) notes the “daunting” challenges of customer delivery, with costs of simply delivering groceries ranging from US$10 to US$20 per order in some circumstances, and reminding us of the spectacular collapse of ‘Webvan’, an online grocer that went bankrupt after reaching a market capitalization of over US$5Bn, while only producing sales of less than $400m. This collapse was partly tied to Webvan’s promise of delivery within a pre-specified window of 30 minutes, leading to a logistical challenge that they simply could not handle (Boyer, 2004).

3.5 Key Messages:

Narrow delivery windows have a significant effect on mileage for freight and goods operators. If tight windows (e.g. 1-hour) can be relaxed, the transportation mileage/cost savings can be realistically estimated as 6% per hour added to the window, up to 4 or 5 hour (half day) windows, and as 25% when a 1-hour window is relaxed to 5-hours.

Assessment of the wider implications are challenging, given that reliable data is hard to obtain for the current distribution of delivery windows. However, primary data provided by Route Monkey suggests that short windows (1 or 2 hours) may currently account for 20% of delivery scenarios, while the continued development of online commerce seems set to cause that to increase sharply in the short to medium term. If this rises in line with the expected growth in e-commerce (hence shifting a portion of delivery-to-store to delivery-to-customer, a fair estimate of the distribution of delivery windows in 2020 would be 30%.

4. Benefits of asset sharing

4.1 Introduction

While CVRS can lead to improved operational efficiency, there are limitations to what can be achieved for a single organization. For example, as most freight travels in only one direction, there can be high levels of empty running as operators are unable to find a return load. This issue is exacerbated by geographical imbalances in freight traffic between different countries. For example, in 2003 around 130,000 lorries travelled empty between Scotland and England, as 31% more tonnage of freight was moved in the opposite direction [McKinnon and Edwards in Green Logistics 2010]. Higher levels of vehicle load utilization have been found to be achieved through collaboration with other companies [McKinnon in Global Logistics 2010]. High profile companies such as Nestlé and United Biscuits have been increasingly employing horizontal collaboration such as sharing transport capacity to reduce empty journey legs. This has caused awareness and driven the appetite of others to employ freight sharing strategies.

There are several asset sharing approaches, but for this report it makes sense to characterize three kinds:

(i) matching 'backhaul' with coinciding loaded trips;
(ii) joint consolidation centers (essentially, strategically situated shared depots);
(iii) joint optimization of vehicles and depots.

The first revolves around 'backhaul'; when a truck has delivered a full load from A to B, 'backhaul' refers to the return trip, where the same truck would normally be travelling empty from B to A. Correspondingly, another loaded truck – perhaps from the same fleet, or owned by an entirely different company – may be travelling from B to A. The concept of matching backhaul with coincident loaded trips refers to replacing these two trucks with one. In the simplest case, our original truck would travel loaded from A to B, deliver the load, then reload with the contents of the matched truck, and then return to A. This may involve two empty trips between depots in the environs of each of A and B, however the overall reduction in 'empty miles' will usually be extensive.

The second type of asset sharing strategy is exemplified by 'urban consolidation centers' (UCCs); these are facilities – perhaps located at an airport or near a major shopping Centre – that can be used by multiple operators to deposit all deliveries for (typically) the surrounding urban region. Local services then sort and consolidate the good and deliver to final destinations. UCCs can reduce the total distance travelled in urban areas, however, there are scenarios in which they can actually increase delivery costs (Greening, 2015). Nevertheless, Allen (2012) reveals several benefits derived from UCCs. These include reduced mileage of between 60% and 80%, and reductions in GHG emissions of between 20% and 80%. UCCs also bring additional benefits in the form of reduced congestion, and in some cases a reduction in delivery time. However, UCCs are well-understood and potentially already slated for high levels of take-up between 2020 and 2035 (as concluded in Greening (2015) following literature review and engagement with focus groups). Beyond high take-up of existing UCCs, further penetration of the UCC concept means building additional ones; the cost-benefit analysis of the latter is highly complicated and location dependent. For these reasons, we do not consider UCCs further in this report.

The third approach, joint optimization of vehicles and depots, essentially involves two (or more) fleets working closely together, sharing a large portion of their joint resources to optimize the service of their current delivery tasks. This style of asset sharing is less evident in practice than the previous two. However, the barriers to operation are primarily imagination, business models and appropriate ICT, rather than any capital expense, while the savings in cost and mileage can be quite significant. In this report, we suggest that the presence of existing cross-business arrangements, such as those underpinning backhaul, provide clear evidence that further more extensive collaboration can be envisioned. Note that 'joint optimization of vehicles and depots' does not simply refer to combining the first two approaches. Instead, the notion at play is that we treat the combined resources as if they were those of a single fleet operator, so that any vehicle in the combined fleet can serve any of the required deliveries, while the goods associated with both fleets are present at each of the depots. Essentially, this means that each fleet's depots serve as a consolidation Centre for the combined fleet's goods, while the schedule optimization task is able to ignore the 'original' affiliation of each resource.

The aforementioned scenarios could lead to large benefits. For example, if fleet A is based at Los Angeles (LA), and fleet B is based at Las Vegas (LV) (an 8-hour round trip). However, while some of fleet A's and fleet B's deliveries are within 1 hour of their own base, fleet A has several customers in Las Vegas, while fleet B has several customers in Los Angeles. If these two fleets combined their resources, the result would be to eliminate almost all of the 8-hour round trips between these two cities, with joint reduction in mileage that could approach 90% or more. To achieve this 'Milk-run' style arrangements need to be in place, and large loads would be transferred between the LA and LV depots perhaps once per week. Any associated additional cost would be surpassed by the daily benefits of fewer trucks, drivers and fuel used.

In the more general case, the potential benefits may be less immediately obvious; however straightforward mathematical insight indicates that vehicle/depot sharing invariably reduces the average distance from depots to customers, and we can therefore expect benefits in all cases. Consequently, two questions arise: (i) how frequently are the benefits sufficient to motivate the fleets to make the necessary arrangements to combine? (ii) if so, what are the appropriate business models to underpin the combined operation? Modelling was performed in order to address the first of these questions, and is summarized below.

4.2 Evidence from modelling

As we have suggested, sharing assets can be characterized into three main approaches: (i) vehicle sharing via 'matching' of coincident light and heavy loads for selected long journeys; (ii) depot sharing via joint use of consolidation centers; (iii) combined vehicle and depot sharing via joint optimization with vehicles and depots shared. The road freight industry already utilizes the first two approaches. Their associated benefits can be estimated from a range of real data and previous modelling exercises. The third approach is much less evident in practice, and it is consequently difficult to obtain estimates of its impact. We therefore focused on this third approach for the modelling in this report.

Two sets of modelling experiments were performed. First, using real data from four fleets that operate in the UK, pairwise combinations of these fleets were optimized, to assess the potential benefits of collaboration. To investigate what benefits might arise in electric vehicle (EV) utilization, half of each fleet was additionally simulated being EVs. In a further set of experiments, a set of five simulated fleets were optimized to identify the benefits of all potential combinations (ranging from all pairwise combinations, through to the combination of all five fleets). This set was repeated for both the European and USA contexts.

In the first set of experiments, fleets (based on real data) were modelled were as follows:

1. Two UK-wide fleets, A (24 vehicles) and B (25 vehicles), all diesel, each with 88 jobs at different locations (176 locations altogether)
2. The same two UK-wide fleets now half-EV and half-diesel vehicles.
3. Two London fleets, C (8 vehicles) and D (8 vehicles), all diesel, each with 50 jobs at different locations (100 locations altogether)
4. The same two London fleets now half-EV and half-diesel vehicles.

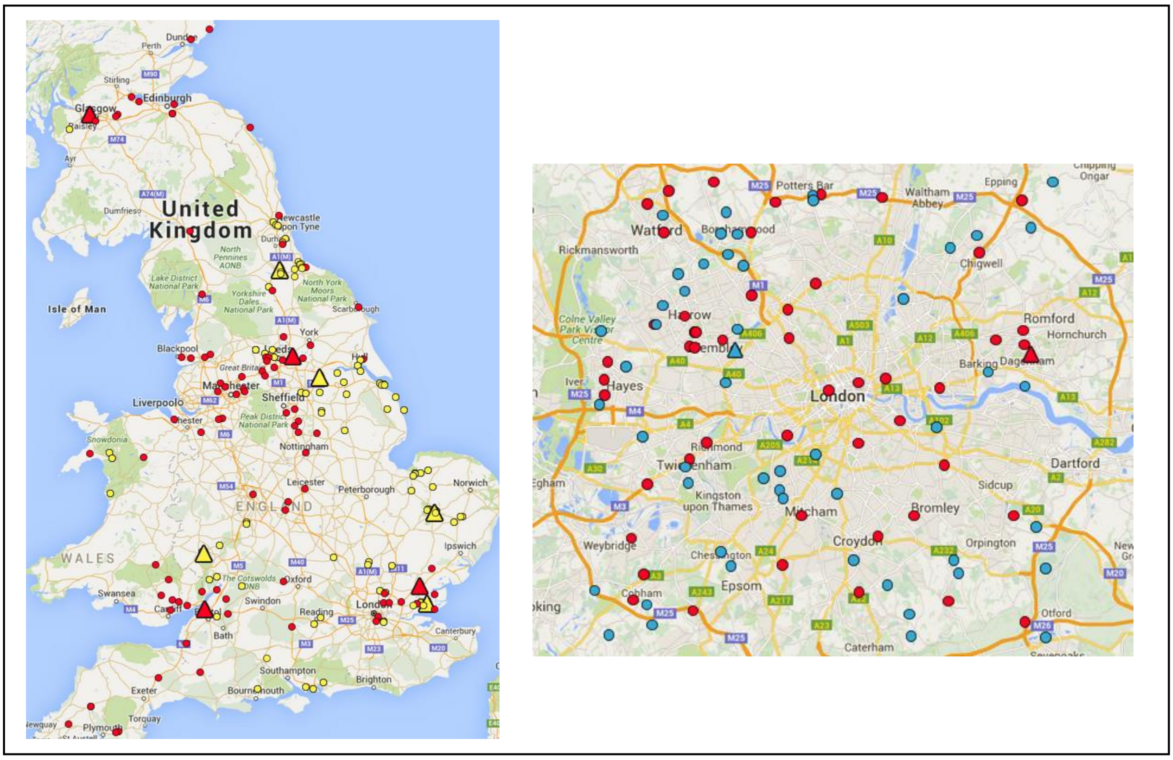

Figure 5: Fleets used in first asset-sharing experiments. Left: UK wide fleets A: customers are red circles, depots are red triangles; and B: customer's yellow circles, depots yellow triangles. Right: London fleets C (red) and D (blue)

Table 6 summarizes the findings from four scenarios using these fleets. Note that the reference comparisons (against the individual fleets working only with their own resources to serve their customers) are always optimized.

Table 6: Outcomes from modelling of collaborations between fleets pictured in figure 5

Scenario 1: UK-wide fleets, all diesel	
Cost savings from collaboration of fleets A and B	20%
CO_2/mileage savings from collaboration of A and B	19%
Scenario 2: UK-wide fleets, half diesel half EV	
Cost savings from collaboration of fleets A and B	22%
mileage savings from collaboration of A and B	25%
CO_2 savings from collaboration of A and B	64%
Scenario 3: London fleets, all diesel	
Cost savings from collaboration of fleets A and B	22%
CO_2/mileage savings from collaboration of A and B	36%
Scenario 4: London fleets, half diesel half EV	
Cost savings from collaboration of fleets A and B	14%
mileage savings from collaboration of A and B	21%
CO_2 savings from collaboration of A and B	63%

The outcomes of the first set of experiments clearly show the potential benefits of collaboration between fleets, whether they are arbitrarily chosen to operate in the same country (A and B) or whether they both specialize in the same city (C and D). We see improvements in mileage of around 20% or better in each case. The improvements in CO_2 emissions naturally match those from mileage in the 'all-diesel' scenarios 1 and 3. However in scenarios 2 and 4, we see a substantial improvement in CO_2 emissions; this arises from a sharp increase in EV utilization that is facilitated by the collaboration. As argued earlier, the mathematical intuition behind the benefits of collaboration is underpinned by the fact that collaboration reduces the average trip time, since it reduces the average distance between a depot and a customer. In the cases of scenarios 2 and 4, this reduction makes the difference between cost-ineffective and cost-effective operation of EVs, and we consequently see their utilization rise sharply.

In the second set of asset sharing experiments, a set of five simulated long-haul continent-wide fleets were optimized to identify the benefits of multi-national co-operation, and the full range of potential combinations was tested, ranging from all pairwise combinations, through to the combination of all five fleets. This set was repeated for two different geographic scenarios: Europe and USA, based on the inter-city distance matrix for a set of major cities in each case (24 in Europe, 31 in USA).

Table 7: Modelled continent-wide collaboration between multiple fleets

Improvements in mileage (compared to the individual fleets working on their own)	Mean	Lowest	Highest
Europe			
Collaboration of 2 fleets	42.9%	31.4%	52.7%
Collaboration of 3 fleets	61.8%	57.3%	66.5%
Collaboration of 4 fleets	63.6%	58.2%	70.0%
Collaboration of all 5 fleets	70.0%	n/a	n/a
USA			
Collaboration of 2 fleets	15.9%	6.4%	31.1%
Collaboration of 3 fleets	35.6%	18.3%	44.5%
Collaboration of 4 fleets	37.1%	21.1%	56.3%
Collaboration of all 5 fleets	38.7%	n/a	n/a

The results shown in Table 7 come with several disclaimers, arising from limitations in the modelling. In particular, customer city locations were chosen at random for each fleet, and may be particularly far flung for an individual fleet, favoring the results for combining resources. In addition, depot location per fleet was randomly chosen, and may therefore be unrepresentatively located. The modelling also involved various simplifications, and represents a small sample of the range of investigations and sampling that could be done to provide confident estimates.

Nevertheless, the potential benefits of collaboration are clear, and two key findings emerge: first, the range of benefits, though always significant, is highly sensitive to geographic context. Intuitively, the larger gains in the European context come from the more complex geography, with a wider range of travel distance between the locations modelled; this leads to more difficulty for individual fleets to cover distant customers, and hence greater fruits from collaboration. Second, independent of geographical context, rapidly diminishing returns are seen as collaboration goes beyond two fleets. However, the benefits for each new fleet to join the collaboration remain significant. Overall, the two-fleet collaboration results for the USA context – in this case more similar in geographic complexity to the UK than the continental European context – seems consistent with our finer-grained modelling based on UK data.

4.3 Further associated evidence

With regard to 'backhaul', Nestlé (a member of this working group) report the operation of several 'static circuits' in their logistic operations across Brazil. These static circuits are sophisticated examples of the style of asset sharing in which empty trips are matched with coincident loaded trips. The concept is illustrated in Figure 6.

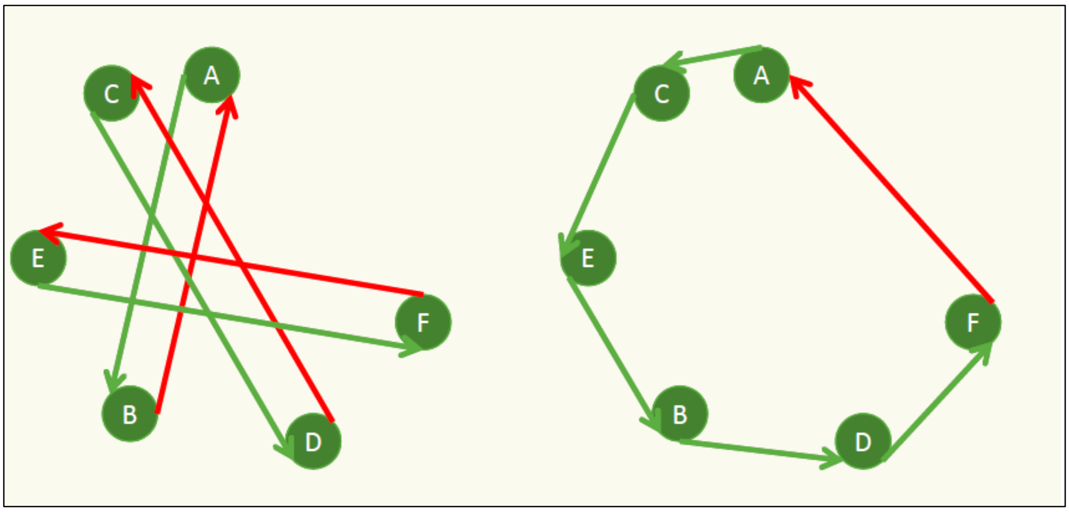

Figure 6: replacing backhaul with 'static circuits'

The traditional arrangement for freight transport is illustrated on the left-hand side of Figure 6. This image shows three separate delivery routes, in each case the delivery trip is shown by the green arrows, while the red arrow shows the empty trip back to base. With appropriate vehicle sharing and loading/unloading arrangements in place, these trips can be served instead by a static circuit, as shown on the right. This circuit serves all of the required deliveries, and involves only one backhaul leg, significantly reducing the empty miles of the traditional arrangement.

In their Brazilian operations alone, in which 30 static circuits are in operation, Nestlé have been able to reduce CO_2 emissions by 7%, saving 436 tons of CO_2 per cycle. Meanwhile, the cost and time savings for each individual circuit are, on average, 32% and 30% respectively. Dominance of longer trips in the Brazil operations leads to a solid overall saving of 7% in emissions, however the savings for individual routes are naturally larger for the shorter trips, since these represent easier opportunities for the diversion of an otherwise empty vehicle. However, it may well be possible to scale up the 30% savings in shorter trips by matching longer backhauls with trips made by other operators with which Nestlé currently does not interoperate.

A significant part of UPS's sustainability efforts has been in filling backhaul freight trips. Coyote (a UPS company) specializes in matching empty trucks on backhaul legs with freight that needs to be moved, using internally developed technology that strategically matches shippers' underutilized assets with Coyote's freight network. Coyote filled almost 970,000 backhaul trips during 2012-2014. These trips eliminated approximately 649 million empty backhaul truck miles from American highways. In addition to freeing up roads, Coyote's services have helped to reduce trucking emissions by over 1 million tons of CO_2 over this same period. An integral component of Coyote's backhaul utilization business model is their 'Private Fleet Service', which works to eliminate empty backhaul miles and reload fleets with revenue-generating backhaul freight. In 2015, this service eliminated 40 million redundant miles; prevented 70,294 tons of CO_2 exhaust; and created new revenue for shippers. UPS's private fleet of 100,000 vehicles currently drives more than 3.3 billion miles each year to transport and deliver customers' freight and packages in the USA. Coyote's activity has directly resulted in only 15% of the total miles travelled by UPS being empty. The remaining empty miles can be mainly attributed to the need for repositioning and balancing assets throughout their ground transportation network. Presently the industry average is 28%, hence indicating that backhaul-centered sharing strategies can achieve benefits of 13%.

The reported mileage saved by UPS is double that reported by Nestlé. This result is consistent with the understanding that Coyote's strategies often go beyond basic backhaul-matching into the area of 'joint optimization' mentioned above. Meanwhile, additional evidence for pure backhaul-centered sharing is consistent with Nestlé, with Greening (2015) citing 8% savings in mileage and fuel. However, this result is independent of relaxation of timing constraints that may otherwise have been in operation; without that, backhaul opportunities may drop to just 2%, especially for shorter trips (Greening, 2015).

Collaboration across companies has recently been met with increasing acceptance in the freight sector. For example, the EU-funded CO3 project (Collaboration Concepts for Co-modality), focused on developing qualitative tools for logistics horizontal collaboration in Europe. A survey across 100 industry players found that collaboration is seen as a major next step in supply chain optimization to reduce costs and carbon emissions, but a structured framework to assist in a paradigm shift towards collaborative approaches is required. A framework was proposed involving a neutral trustee and a mechanism for allocating the savings (gain sharing) amongst the partners to ensure a fair and stable collaboration. Test projects found that an effective horizontal collaboration can generate 10-15% transport cost savings and even more significant CO_2 reductions.

Meanwhile, Pan (2013) looked at vertical and horizontal collaboration in the context of pooling supply chains. This was motivated in part by certain drawbacks that were noted about 'traditional' freight consolidation, which tends to take place in a local and fragmentary way, using carriers and third-party logistics. They concluded that the pooling of supply chains at the strategic level could lead to a 14% reduction of CO_2 emissions with road transport, and of 52% reduction with joint road and rail transport. However, such an approach demands further and long-term collaboration between the actors of supply chains (suppliers and retailers in this case).

4.4 Wider implications

The benefits of asset sharing are clear, with savings in GHG emissions ranging from an indicative ~7% to ~30% depending on the degree to which operations are jointly optimized, and the number of independent operators involved in the alliance Assessment of wider implications of promoting take-up of this activity is challenging, due to the dependence on the extent to which asset-sharing arrangements are already in place. However, it seems entirely reasonable to suggest that the vast majority of potential asset-sharing possibilities are *not* in place. It seems clear that most vans and trucks clearly only carry items from their own company; meanwhile, the experience of Route Monkey Ltd, and other fleet optimization providers, is that of a client list overwhelmingly dominated by single-fleet clients seeking optimization for their own deliveries.

Asset sharing has been seen in selected cases of very large operators (such as UPS and Nestlé), where the size of operation and the resources of the company provide both the motivation and intellectual resources to set up such arrangements. However, such large operators represent both a small proportion of fleet operators, and a surprisingly small proportion of vehicles on the road. Recent UK statistics indicates that at least 90% of HGV vehicles on the road in the UK belong to fleet operators with just one to ten vehicles (Statista, 2016). Similarly, fleet operators in the US with more than 100 vehicles represent less than 10% of fleets in the California region (Golob & Regan, 1999). Geographical variance is clearly large; however, we would argue that a reasonable and very cautious assumption based on this evidence is 85% of commercial vehicle miles are operated without the involvement of any asset sharing arrangements.

It remains to consider how realistic it is to expect that asset sharing arrangements will be taken up in future by this large pool of candidates. In addition to the examples and studies cited already, it is reported in [McKinnon in Global Logistics 2010] that many companies who previously used dedicated truck services now allow their providers to carry other companies' goods. Company-sponsored studies of shared-user services in the automotive, consumer electrical and clothing sectors in the UK have indicated that this strategy can reduce truck-km by around 20%, in each case replacing 4 or 5 dedicated services. Meanwhile, a recent UK survey amongst UK supply chain representatives found that 78% of retailers and 71% of suppliers believe reducing road miles to be either “the biggest” or “a significant opportunity” for cost savings in their supply chain [Reducing Wasted Miles, ECR UK, 2015]. While 31% of those surveyed considered intelligent routing and scheduling to be an important option to achieving this reduction and lastly asset sharing was cited by 55%. Concerning vertical collaboration, ‘Collaborative Transportation Management’ (CTM) is a US initiative to encourage collaboration and information sharing between manufacturers, retailers and carriers to cut transport costs while improving service quality. This gives carriers an extended planning horizon, allowing some to increase utilization of regional fleets by 10%-42% due to complementary backhaul opportunities [McKinnon in Global Logistics 2010, Esper and Williams 2003]. A recent review of CTM suggested future research directions include developing “behavioral models to capture the interactions among collaborative parties”, and “an incentive alignment to persuade collaborative parties to behave in ways that are best for all by distributing the risks, costs, and rewards fairly among the involved parties” [Okdinawati et al 2015].

The potential for asset sharing globally depends on the state of maturity of the logistics market in different regions. Colliers International (2015) noted that “As the expanding volume of e-commerce translates into growing demand for more sophisticated warehousing and distribution facilities, joint ventures between retailers, freight and logistics providers, developers and institutional real estate investors is going to be one of the most interesting trends that will foster further market evolution for the foreseeable future”. Colliers International identified four evolutionary positions for the logistics real estate market, based on pace of demand growth, sophistication of logistics requirements, degree of competition and business operating models in use, to which it mapped existing markets as of 2015:

- Beginning – Southeast Europe, Africa, UAE, India
- Growth – China, Japan, Russia, Turkey, Brazil, Mexico
- Consolidation – Singapore, Hong Kong, Taiwan, Eastern and Southern Europe
- Strategic Alliance – UK, Western Europe, Nordics, Australia, North America

Arguably, extensive asset sharing may only be a real possibility in a market at the Strategic Alliance stage (as in earlier stages the parties will be less inclined to consider cooperation). In terms of the 2020 position, we might expect Chinese coastal markets (Shanghai) to be the most likely to reach the Strategic Alliance stage first, alongside Taiwan, Singapore and Hong Kong. Similar can be said for Southern Europe, where competition is intensifying, logistics operators use service differentiation to secure market share, and strong intermodal hub potential may create alliances involving rail freight. Meanwhile, Russia, China and Japan seem most likely to reach Consolidation phase towards 2020, alongside major cluster cities in Brazil and Mexico (due to high e-commerce growth).

4.5 Key messages

Asset sharing will result in saving 7-70% of GHG emissions depending on the degree to which operations are jointly optimized, the number of independent operators involved in the alliance, and the geographic context. Backhaul-centered asset sharing can lead to emission benefits around 8%, while more extensive sharing of assets between two operators can lead to 15—30% emission and mileage saving, with higher benefits achievable in some cases. Based on the modelling, we would propose a tentative average of 20%, varying significantly with details, recognizing that pairwise collaborations are likely to be more numerous and achievable in the short to medium term. Meanwhile, with much imagination and extrapolation, yet laced with caution, we suggest that 85% of current commercial vehicle miles are yet to benefit from such measures.

5. Benefits of alternative fuels

Diesel and petrol are responsible for the great majority of CO_2 and other GHG emissions that can be attributed to the transport sector. The development of alternative fuels, especially those that can reduce or eliminate GHG emissions without undue cost (or other) consequences, is therefore of great interest. Drawing from a range of sources, in this section we will summarize what seem to be the benefits of a range of alternative fuels (including electric vehicles), considering also their drawbacks.

An important aspect of the drawbacks in the case of fuels is 'well-to-wheel' emissions profile. When we considered logistical measures in sections 2—4, only *on-road* emissions were relevant, since only these can be impacted by, for example, re-planning a route. When we consider alternative fuels, however, the carbon footprint impact of the alternative fuel has two significant components: (i) the familiar 'on-road' emissions, and (ii) the so-called 'well-to-wheel' emissions, which characterize the carbon impact of the fuel's production process. As we will see, in some cases the on-road benefits may be minimal, while at the same time the 'well-to-wheel' benefits are more than substantial enough to warrant their consideration.

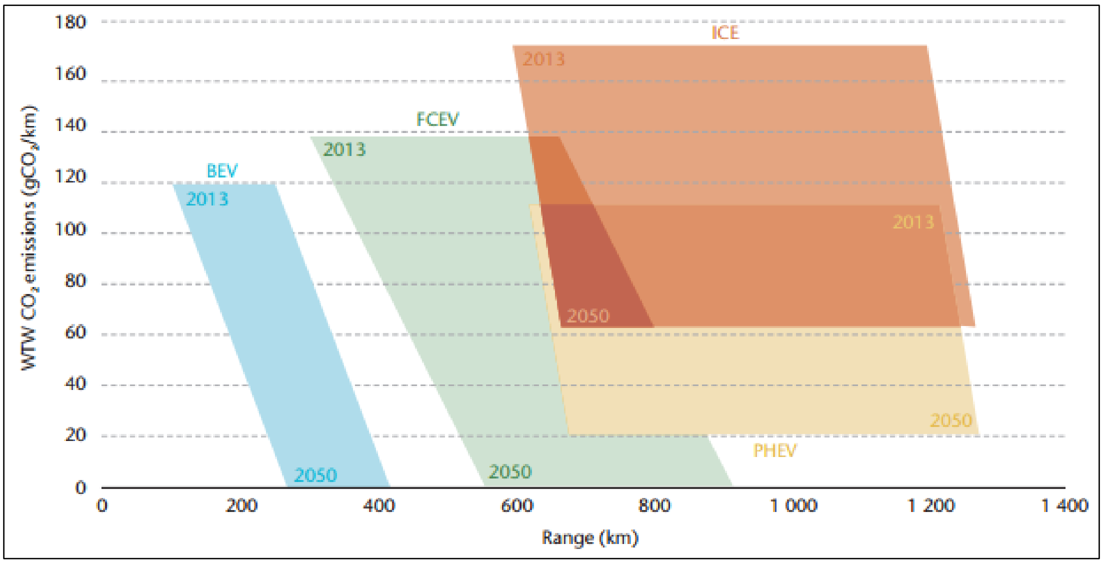

Figure 7: Driving range and WTW CO_2 emissions across different powered vehicles IEA (2015)

When comparing the well-to-wheel emissions across different alternative fuels and technologies it is important to note that the current commercially available technologies are not all best suited to different end uses. Figure 7 illustrates the differences in driving range and WTW CO_2 emissions across battery electric vehicles (BEV), fuel cell electric vehicles (FCEV), plug-in hybrid electric vehicles (PHEV) and internal combustion engines (ICE). Similarly, other performance characteristics such as power can differ and must therefore be taken into account when determining the energy vector and drivetrain configuration best suited for different road freight transport duty cycles. A further illustration of this choice of technology for different duty cycles is illustrated in Figure 8 showing the operations of the UPS' "Rolling Laboratory".

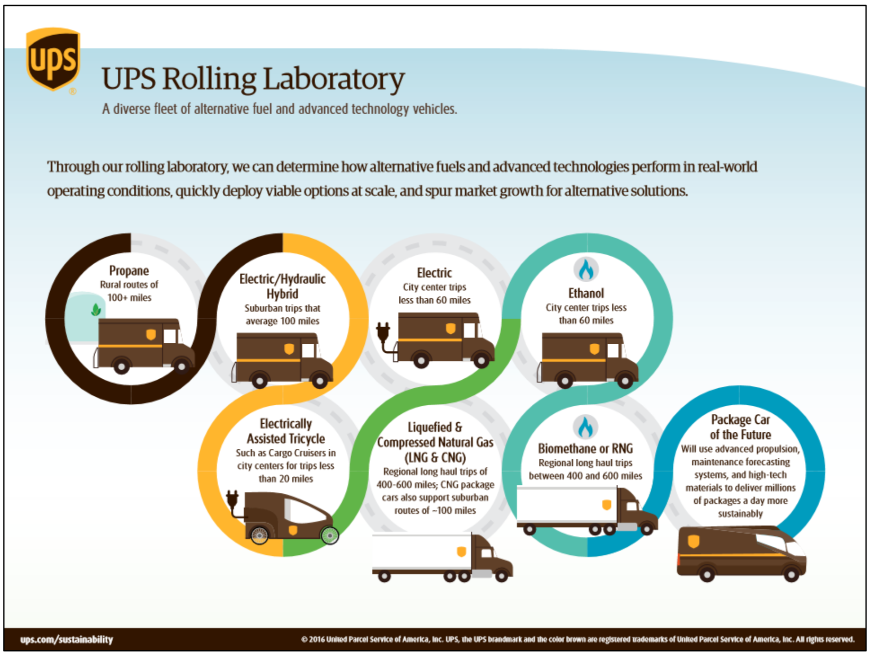

Figure 8: UPS rolling laboratory (UPS, 2016)

5.1 Fuel Additives

Although fossil fuels cannot decarbonize transport, they can be part of the transition to net zero emission economy. A first step in the transition to lower carbon fuels is to improve the performance of vehicles using internal combustion engines with fossil-based fuels. The option of improving engine design to allow more efficient use of fuel will be discussed in the following chapter. However, the fuel formula itself can have a positive impact on vehicle efficiency. Additives to gasoline and diesel fuels can improve the fuel efficiency (and therefore reduce CO_2 emission) up to 4.4% [Total, 2016].

Fuel additives counteract engine fouling from the accumulation of deposits affecting sensitive parts. Among other components, additive fuels have been enriched with detergents, which clean and keep the main components of engines (injectors and inlet valves) clean, thus improving performance compared to fuels without additives. A key benefit of additive fuels is the ease with which to implement this solution across the existing fuel distribution infrastructure and vehicle pool. Hence, the use of additives with fossil fuels is a quick way to reduce CO_2 emissions (through the reduction in fuel consumption) and will be part of the early solutions deployed in the future low carbon solutions mix which also includes alternative fuels and electric vehicles.

5.2 Biofuels

Biofuels are naturally-sourced fuels that, essentially, are 'grown' via agricultural means. 'First-generation' biofuels were derived from sugar, starch, and edible oils, and thus were (and are) in competition with the use of arable land for food production. However recent innovations in fuels has seen this sector move towards alternative feedstocks and processes with limited or no competition for use of arable land while also significantly improving the well-to-wheel emissions performance. These include novel plant feedstocks (e.g. woody biomass, switchgrass, or algae), use of waste streams (e.g. agricultural residues, food processing waste and CO_2) and new biological or synthetic pathways (e.g. power-to-liquids and biotechnological processes). Coupled with tax incentives and technical advances, the newer fuel pathways have led to sharp growth in production since 2012. However, more time for further technical development is needed to allow industrial scales of advanced biofuels to be commercially available. Moreover, the industrial development of advanced biofuels benefits from 1st generation biofuel development as there are synergies between the technologies and incentive structures created to promote 1st generation commercialization. Though first-generation fuels remain a large portion of the market, other feedstock and pathway combinations are being widely researched, and seem set to improve cost, yield and efficiency, while meeting a broad range of sustainability criteria [Jones et al, 2012; Aydrogan et al, 2014].

Biofuels tend to enjoy a wide take-up since they can be blended with conventional fuel with no requirement for alterations to the vehicle (if the biofuel component is in the region of 10% or less), and can be delivered with conventional refueling infrastructure. Higher blend rates, even up to 100%, are enabled by biofuel pathways that produce so-called 'drop-in' fuels which are chemically identical to their fossil fuel counterparts (gasoline, diesel and jet kerosene), although current production of these is still much lower. Another, immediate benefit of biofuels is that their CO_2 emissions tend to be considered 'net zero', since these are offset by the CO_2 absorbed during production. Finally, a significant benefit of biofuels is the ability of current fuel distribution infrastructure to adapt to biofuels. However, their beneficial emissions impact is reduced at low concentrations, and could present a slight negative impact in NOx emissions. An indicative recent review is provided by [Mofijur et al., 2013] and they also found that viable blends reduce HC emissions and CO emissions by 4%—10% and 16%—25% respectively, however NOx emissions increased by 3%—6%. Meanwhile, the corresponding figures for pure biodiesel are estimated as a 70% reduction for HC and a 50% reduction for CO, while increasing NOx emissions by 10% [AFDCa, 2016].;. For diesel, there is not major incompatibly between injection system and fuel with high rate of bio-component, however some points like performance of post-treatment system for example have to be checked.

5.3 Hydrogen

A Hydrogen fuel cell is a device that generates electricity by converting hydrogen and oxygen with water being the only by-product. In other words, tank-to-wheel GHG emissions in comparison with conventional fuels and others covered in this section (excepting electric vehicles) are reduced to zero emission at the tailpipe. The immediate benefits are obvious, especially in urban areas that suffer from poor air quality; consequently, several cities are either trialing or already operating hydrogen-powered public transport [Hua et al, 2014].

However, considering the 'well-to-wheel' CO_2 emissions of the hydrogen supply chain one finds a different picture. Industrial production of hydrogen is an energy intensive process today. The main (and cheapest) approach to hydrogen production, 'steam reforming', involves combining high-temperature steam with natural gas, and the environmental footprint of the resulting fuel derives from the energy used to produce the high-temperature steam. The resulting economic cost of the electricity ultimately delivered by the cell is estimated at four times that of electricity obtained directly from the grid [Bossel, 2006]. The power requirements for the production process could be supplied by renewable generation, however the low efficiency of this process leads to severe concerns as to whether this is a viable use of renewables [Cullinane & Edwards, 2010]. Another possibility to achieve low well-to-wheel emissions for the large-scale production of hydrogen is to implement carbon capture and storage (CCS) with steam reformation, however no such application of CCS exists today. The improvements in electrolyzes which split water into hydrogen and oxygen have seen an interest in combining their operation with the availability of high amounts of variable renewable power generation. A distributed Hydrogen production model based on electrolyzes and surplus wind/solar power could be a viable route to zero-emissions hydrogen production for use in fuel cells.

Moreover, the production of Hydrogen fuel cells currently requires platinum as a catalyst. Production of platinum has several detrimental effects on the environment, ranging from emissions of SO2, ammonia, chlorine and hydrogen chloride, through to long-term groundwater and disposal problems [Dept. for Transport, 2002]. Finally, large-scale penetration of hydrogen as a fuel requires a wholly new refueling infrastructure, requiring significant investment, and strewn with challenges in terms of storage and distribution.

5.4 Natural Gas: NG, LPG and CNG, especially from renewable sources

Natural Gas (NG), Liquefied Petroleum Gas, and Compressed Natural Gas (CNG) fuels are each (on the whole) normally derived from fossil fuel sources, or as a by-product of petroleum refinement and/or gas field extraction. For ease of distribution and use in transportation, they are either subject to liquefaction process (LPG or LNG) or a compression process (CNG) resulting in considerably reduced volume. In terms of on-road emissions profile, the benefits over conventional fuels are modest. On-road CO_2 emissions can be 5-15% less that petrol or diesel vehicles depending on their use but individual company experience suggests generally much lower figures owing to the lower energy content of the fuel. However, on-road NOx emissions are considerably reduced or even eliminated, while also negating the need for particulate matter filters [Cullinane & Edwards, 2010]. Meanwhile, production challenges tend to be on a par with or lower than those of conventional fuels, and consequently these fuels can compete in price for the consumer, especially in terms of bulk deals with local suppliers [AFDCb, 2016]. The pragmatics around vehicle conversion and refueling infrastructure for these fuels are much less challenging than they are for Hydrogen. However, the full distribution infrastructure beyond refueling points are similar in cost and complexity for hydrogen and LNG.

The potential for these fuel sources becomes much more attractive, however, when we look at renewable sources for their production. Renewable Natural Gas (RNG) is produced from biogases that are emitted when organic waste breaks down. In terms of availability, the primary sources are landfill waste, waste from certain agricultural crops and forestry, and manure from farms and dairies [EV, 2012]. For use in transportation, these sources of RNG require removal of impurities (e.g. water and sulfur) and should be compressed before transporting to the point of re-fueling. Benefitting from the same 'net zero' carbon impact of biofuels, renewable CNG (R-CNG) and renewable LNG (R-LNG) display significant improvements over diesel when it comes to 'well-to-wheel', or 'life-cycle' GHG emissions [LFCS, 2009]. In particular, when normalized for energy input in the production process, the production of dairy or landfill sourced R-LNG produces on average only 28% of the emissions of diesel production. The corresponding figure for dairy/landfill sourced R-CNG is 13%. It should also be noted that RNG can be blended with natural gas, allowing the current natural gas infrastructure to cater for the potential growth in RNG availability, keeping overall deployment costs for these technologies low.

5.5 Electric Vehicles

Electric Vehicles (EV) have the same attractive benefit of zero 'on-road' emissions, along with the elimination of engine noise as hydrogen fuel cell vehicles, an advantage especially for last mile use. However, 'well-to-wheel' considerations focus on the fact that the energy stored in the batteries must be produced by conventional means, while manufacture of the vehicles and batteries themselves incurs a variety of environmental costs as for other energies. Hawkins et al [2013] find that the 'global warming potential' (essentially, emissions per km over lifetime) of an EV can vary between 10% and 29% better than conventional diesel vehicles, depending on lifetime mileage, battery type, and assuming a European energy mix, with around half the emissions cost for EVs incurred before the first mile. However, the energy mix used to charge EVs has a great impact on these estimates. IEA data shows that there is a very large range of electricity mixes between countries. According to the primary source of energy used to produce electricity, the savings have important fluctuations, from near zero emission to the level of recent internal combustion engine vehicles (or even above). Samaras & Meisterling [2008] found corresponding savings of 38%—41% predicated on a contemporary US energy mix, and 51%—63% under 'low-carbon' scenarios that correspond to particular times of day and year when using the acclaimed 'GREET' model [Wang, 2001]. To investigate a more aspirational estimate for the near term, we used the latest version of the GREET 'mini-tool' to estimate this value, based on the current energy mix in California. With recent figures at 20% of retail electricity sales, the percent renewables in California's energy mix is ahead of the US average, and expected to rise to 25% by 2020 [CAEC, 2015]. Using the tool, the estimate returned for lifecycle savings in emissions was 71%. In the ensuing ‘key messages’, we compromise with the more modestly aspirational estimate of 63% from the upper end of Samaras and Meisterling’s findings [2008].

Furthermore today, for heavy duty vehicles, the question of both range autonomy and weight burden brought by batteries are critical and will have to be to be resolved in order to avoid operational constraints.

5.6 Key messages

While technology and policy may well advance in future to boost the economic viability of hydrogen fuel cells or biofuels, short and medium term pragmatics seem to favor the recommendation of R-CNG / R-LNG and electric vehicles (EVs) to businesses seeking to meaningfully reduce their carbon footprint quickly at feasible levels of investment. Over the longer term, a mix of advanced biofuels, EVs and FCEVs (both with decarbonized production pathways) will achieve the best GHG emissions reduction results, but these pathways require time for the technologies to reach scale and become more viable. The conversion and infrastructure costs of R-CNG and EV are favorable compared to those for hydrogen, while their emissions benefits profile and fuel costs are favorable in comparison to biofuels; however, it must always be recognized that this is assessed against a constantly changing landscape.

The potential impact of full take-up of R-C/LNG (for the sake of argument) is quantified by first estimating 80:20 (averaged from several sources) for the ratio of ‘heavy duty’ vs ‘light-duty’ commercial vehicle miles. It should be noted that CNG tends to be more suitable for light duty vehicles, and LNG for heavy duty [Westport, 2013]. Using lifecycle average estimates for R-C/LNG, we can estimate that full take-up of R-C/LNG for commercial vehicle miles would lead to an 83% reduction in well-to-wheel GHG emissions in comparison with diesel [LFCS, 2009]. Of the 12.6 million commercial vehicles, currently on the road in the US [IHS, 2016], we expect approximately 2.5 million (20%) of these to be using alternative fuels by now or in the near future (extrapolating from [AFDCc, 2016]). From these the potentially addressable commercial vehicle miles can be estimated at 80%. Similar quantification for the addressable miles from an aspirational full take-up of EVs would follow the same argument, and consequently yields the same figure of 80%. Averaging over the R-C/LNG and EV savings (84% and 63% respectively), and taking into account the addressable miles, we settle on a figure of 58%, representing the ‘high-take-up’ potential impact of alternative fuels in reduced CO_2 emissions from freight transport. While these numbers are considered possible, it should be noted that both the use of RNG and EVs in road freight operations would need to overcome supply and infrastructure barriers. For instance, there is a significant shortfall in supply of RNG and the cost/performance of batteries would need to decrease significantly for heavier truck applications.

6. Benefits of vehicle efficiencies

Independently of logistical measures and fuel type, a range of efficiency measures are available to reduce a vehicle's fuel consumption per mile with modest investment. Such measures range from adoption of specialized tires to smarter operation of in-vehicle heating and cooling, and they have been extensively and comprehensively investigated by a number of transport research organizations. In this brief section, we simply summarize the relatively recent 234-page book produced by the US Transport Research Board in 2010 [TRB, 2010], which detailed the findings of a large expert committee tasked to investigate this topic over 12 months, drawing on a range of specialized consultants and over 100 associated reviews and other publications.

The efficiency measures in this theme broadly fall into five categories. The first, 'Intelligent vehicle', refers to the exploitation of telematics, GPS, vehicle state and environmental information via intelligent software. In the context of fuel reduction (rather than safety), the benefits of 'intelligent vehicle technologies' come largely through predictive and adaptive cruise control, and through smart navigation. Intelligent cruise control systems will take into account speed, distance to and speed of the vehicle ahead, incline and other factors, and ensures fuel consumption for acceleration and time in lower gears is minimized. Smart navigation makes use of current traffic information, including information relating to traffic levels further along the route to the destination, and will suggest more fuel-efficient routes if and when available. (note that this is complementary to route optimization as discussed in earlier sections, which concerns the sequencing of deliveries, rather than the precise route between successive deliveries). Across these approaches, [TRB, 2010] found (via summary of several studies and simulations) between 9% and 15% savings in fuel consumption could be achieved.

The second measure, 'aerodynamics' refers to modifications that can be installed to reduce air-resistance. In tractor/trailer combinations, there are four chief areas that can be addressed to alleviate aerodynamic losses: the profile of the tractor, the gap between tractor and trailer, the trailer's 'skirt', and the trailer base (at the lower back of the trailer). For unit costs of around $1000 each, shaped components can be installed in each of these areas (e.g. aerodynamic bumpers), which individually can deliver fuel consumption savings ranging between 2% and 10%. Overall, across a range of vehicle types and combinations of aerodynamics solutions (including vehicles that are already highly aerodynamic as delivered), this measure can produce savings between 3% and 15% [TRB, 2010]. Novel approaches today include both increasing the length of articulated trucks as well as "platooning" whereby individual trucks drive in very close consecutive arrangements enabled by semi-autonomous driving systems. Such solutions reduce the aerodynamic resistance per ton of goods transported (Lammert et al., 2015).

The third, 'rolling resistance', relates to improved tires (in terms of weight reduction and/or tread), along with specifics of their arrangement in multi-axle vehicles, and the maintenance of tire pressure. Rolling resistance itself refers to the tire and its deformation when rolling and the rolling resistance force increases with load. Overcoming the rolling resistance force requires around one third of the engine power for a long-haul heavy-duty truck TRB [2010]. Mainly through the potential for better tire materials and pressure maintenance combined, TRB [2010] concluded that achievable savings ranged from 5% to 9% for this measure.

Fourthly, 'weight reduction', refers to the replacement of components with lower-mass alternatives (e.g. replacing standard panels with aluminium composite versions). Weight is a significant element in the power needed to move the truck (in part owing to the increased rolling resistance force discussed above), however it's effect is primarily evident during acceleration, and otherwise somewhat mitigated by momentum. An empirical study found that doubling a truck's weight leads roughly to a 20% reduction in fuel efficiency [Capps, 2008]. Much of the current vehicle fleet is reasonably weight-efficient by design. However, decisions to add fuel-efficiency technologies (such as aerodynamics modifications) are complicated by the *added* weight from this equipment. Nevertheless, opportunities for affordable improvements are available for elements such as doors (cab and trailer), rails and wheels as new designs and materials emerge in the market. Referring primarily to the study and review on this topic from [TIAX, 2009], TRB [2010] summarizes the available fuel reduction savings between 2-5%.

The last measure in this theme is, 'auxiliary loads', concerns minimizing the power demands for systems other than driving the wheels, such as power steering, braking, alternators and fans. Air-conditioning systems, especially for cooling, tend to be the main power draw, while systems such as electric wipers cause negligible load. As an indicative figure, these systems account for around 2.5% of fuel consumption. However, the precise value varies greatly with vehicle type, use and environment; for example, a transit bus in a hot climate can spend up to 25% of its fuel in air conditioning. To some extent these auxiliary loads can be reduced with smarter control systems, however the primary route towards reduced fuel consumption is replacement with more efficient subsystems. Often this means replacing a mechanical unit with an electrical one. For example: a mechanical power steering system uses a continuously operating belt-driven hydraulic pump; in contrast, a replacement electrical power steering unit would only consume power when needed. Overall, reduced fuel consumption in the area of auxiliary loads is 1%—2.5% [TBR, 2010].

6.1 Key messages

For any freight vehicle, a range of opportunities will typically exist to reduce fuel consumption by modifying its components, systems, and on-board software. Being modifications (and not, for example, complete vehicle replacement), these opportunities can be considered pragmatic and affordable. Their applicability and impact can vary wildly as a result of several factors, ranging from the age of the vehicle to the climate in which it operates.

Nevertheless, it is valuable to attempt an indicative overall conclusion for the benefits available via these measures. As a first step, we note that each of individual themes discussed in this section is broadly independent of the other, and we can expect the savings from a combination of these measures to be close to the sum of the individual contributions. If we take the mid-range of benefits for each theme and combine them, we reach 32%. However, the picture is more complex; for example, weight reduction interacts positively with rolling resistance leading to a benefit that is greater than the sum of parts, however this extra benefit may be limited by aspects of aerodynamics.

It is possible to argue that up to 100% of vehicle miles may be addressable, simply because the market for new systems and components (e.g. as new carbon fiber composites become available) is vigorous, and vehicles can be continually updated. However, such an aspirational percentage for addressable miles has to be set against the fact that the fuel consumption benefits for newer vehicles, and/or those that are regularly updated, will tend to be in the lower range. Meanwhile, it is clear that commercial fleets currently fail, on the whole, to stay up to date, with the average vehicle age in the US above 11 years [TB, 2015]. This leads us to expect both (i) the level of benefit available to be generally towards the high end, and (ii) addressable vehicle miles to be high. In the end, an estimate of 80% is taken as a compromise, largely by recognizing the combination facts that: (i) that this tends to be the level of addressable miles for other measures we have reviewed, and (ii) fleet operators with the will to instigate efficiency and/or carbon reduction measures at all, will often be minded to implement multiple (if not all available) measures.

7. Benefits of driver training

Finally, eco-driver training is widely acknowledged to be one of the most cost-effective means of reducing fuel consumption and GHG emissions in the road freight sector. Drivers undergoing training as part of the UK government-sponsored safe and fuel efficient driving for HGVs (SAFED) program have, on average, managed to improve the fuel efficiency of their driving by around 7% [Department for Transport, 2006]. The saving that an individual company can achieve will depend on the caliber of the drivers, nature of the delivery operation, age of the fleet etc., and so generalization is difficult. Nevertheless, there is general agreement that driver training must be accompanied by monitoring, debriefing, publicity and incentive schemes to ensure that the 'eco-driving' practices are embedded after the training period. Greening (2015) cites average improvements that vary from 9% on long haul journeys to 5% on urban journeys, consistent with this 7% fuel efficiency improvement average. Further reports consistent with this suggest that the available improvements vary from 5% to 12%, and note that, at least in the UK, eco-driving training is one of the more popular measures being undertaken to reduce HGV fuel consumption [Freight Carbon Review, Department of Transport, 2013]. This has contributed to a significant reduction in carbon intensity amongst members of the Logistics Carbon Reduction Scheme of the FTA (a large UK freight transport association), with average CO_2 emissions per vehicle km down 12% between 2005 and 2013. Meanwhile, the French ministry of Ecology and Sustainable Development 'Voluntary commitments charter' guide to Road Freight transport, reports figures ranging from 3% reductions in CO_2 emissions following initial 'eco-driver' training, through to 10% with the operation of an in-vehicle eco-performance monitoring system. Finally, the UK Centre for Sustainable Road Freight (Greening, 2015) concludes that sustained take-up of driver training programs will account for 2.5 Mt CO_2 reduction in the UK by 2035, placing it on a par with a range of 'logistics measures' such as a backhaul, urban consolidation, and acceptance of night-time deliveries, and telematics. However, they did not include route optimization among these measures.

7.1 Key messages

Driver training can reliably lead to improvements in fuel efficiency of 7%, often a little more, with corresponding reduction in GHG emissions. This measure is already popular and widespread, and relatively cheap for operators to undertake.

8. Summary of Key Findings

We can distil our main findings, arguments and assumptions to the following list:

- Asset/route optimization with modern fleet software will save on average 12.5% of a fleet's transportation costs, and we estimate that 85% of the road freight sector (roughly corresponding to 85% of road freight miles, since take-up seems not to vary with significantly sector), operates routes that are currently un-optimized.
- Narrow delivery windows have a significant effect on mileage for freight and goods operators. If tight windows (e.g. 1hr) can be relaxed, the transportation mileage/cost savings can be estimated as 25% when relaxing a 1hr window to a half-working-day window of around 5 hrs., involving approx. 6% benefit per hour added to the window. We estimate that the portion of deliveries that might be subject to such improvement, if mechanisms can be found to relax the window expectations, will be 30% by 2020; translating this to commercial vehicle road miles is complicated, but simply equating that to 30% of commercial vehicle road miles is a fair starting point.
- Different varieties of asset sharing can produce savings in GHG emissions that range from 7% to 70%, with a tentative average of 20% achievable from pairwise collaboration. A tentatively estimated 85% of current commercial vehicle miles are yet to benefit from such measures.
- Different fuel alternatives have widely varied profiles in terms of infrastructure requirements, costs, on-road and lifetime emissions benefits. Considering these profiles in tandem with the current state of technologies and economic trends, R-C/LNG and EVs emerge favorably, and their widespread adoption could lead to 58% reduction in reduced CO_2 emissions from road freight.
- Vehicle-centric efficiency measures tend to be additive and widely applicable, and could lead to an indicative fuel consumption savings of 32% on average, if multiple such measures are used and the vehicle is updated regularly; considering average fleet age, it seems that these measures could be applicable to at least 80% of commercial vehicles.
- Driver training can reliably lead to improvements in fuel efficiency of 7%, often a little more, with corresponding reduction in GHG emissions. This measure is already popular and widespread, and relatively cheap for operators to undertake. Arguably, there is no great need for WBCSD to add weight to the many pre-existing programs that are encouraging take-up of this activity.

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