DOUBLE-DECK TRAILERS: A COST-BENEFIT MODEL ESTIMATING ENVIRONMENTAL AND FINANCIAL SAVINGS

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Abstract

Purpose: Double-deck trailers could be a key contributor towards the UK's commitment to reducing CO2 emissions towards 2020. A double-deck trailer greatly increases carrying capacity with current vehicle size and weight limits. Double-deck trailers are particularly well suited to retail distribution. This paper introduces a model that calculates the financial and environmental impact of deploying double-deck trailers on a specific set of routes.

Research approach: Based on industry case studies a model is developed which captures the cost drivers of three double-deck scenarios involving the use of a movable-deck trailer and two fixed deck vehicles, one with a tail-lift and the other with an external lift. The case studies identified all the relevant cost drivers and the relationships between them. CO2 emissions are calculated using established methodologies and incorporated into the model. The relationships in the model were validated by comparing the findings with the Continuous Survey of Road Goods Transport data.

Findings and Originality: The study is the first to quantify the comparative benefits of using fixed deck or moving-deck trailers from a financial point of view as well as considering CO2 emissions. The study confirms previous research highlighting the benefit of using double-deck against traditional single-deck distribution.

Research impact: While currently not widely used, the study found that utilising fixed double-deck trailers is a viable option for many operations, especially in the retail sector.

Practical impact: Given a set of routes to consider, the practitioner can easily compare the three scenarios, finding the most cost effective and most environmentally-friendly option. Existing double-deck users can benchmark their operation using the model. It is flexible enough to allow comparison of a wide range of distribution networks and routes.

Keywords: Double-deck trailer, distribution, cost-benefit analysis

Introduction

The use of double-deck trailers offers one of the best opportunities for improving the efficiency of the UK freight sector. Goods are loaded on two levels rather than one, effectively doubling volumetric capacity per trailer (Department for Transport 2005). Double-deck trailers are becoming increasingly widespread, as 3PLs and retailers see them as a viable distribution option. They offer financial benefits as well as a reduction in environmental impacts. Double-deck trailers could be a key contributor towards the UK's commitment to reducing CO2 emissions towards 2020.

There are many different double-deck solutions available, characterised by the manner in which the top deck is loaded or unloaded ranging from hydraulic moving decks to tail lifts and external lifts. A previous double-deck study by McKinnon and Campbell (1997) established a taxonomy of double-deck trailers. The main purpose of their study was to estimate the potential of double-deck distribution in the UK and the corresponding in lorry traffic levels.

Based on a series of case studies, this paper introduces a model that calculates the financial and environmental impact of deploying double-deck trailers on a specific set of routes. The model further guides the decision-making process by evaluating different types of double-deck design.

The study is the first to quantify the comparative benefits of using fixed deck or moving-deck trailers from a financial point of view as well as considering CO2 emissions savings. It confirms previous research highlighting the benefit of using double-deck rather than traditional single-deck trailers.

When is double-deck distribution suitable?

Double-deck distribution is possible in the UK as there are fewer vehicle height restrictions than in other European countries. Bridges and tunnels offer sufficient height clearances to accommodate double-deck trailers which are typically between 4.8 and 5 meters tall. In contrast, across most of the European mainland, truck heights are restricted to 4 - 4.2 metres. Lower bridges or tunnels in the UK require detours that can reduce the efficiency of double-deck trailer use. However, minor detours do not significantly impair this efficiency.

Second, the distribution centre should be able to accept tall double-deck trailers. These trailers can be designed to work with specific loading bay heights, and external lifts can be fitted to overcome access problems.

Third, double-deck trailers are often restricted on payload weight they are is heavier than a single-deck, while operating at the same gross weight limit. Double-deck trailers are thus mostly used for the distribution of light goods. In the UK the maximum gross weight for a 6 axle tractor/trailer combination is 44 tonnes. The typical tare weight of the tractor/trailer is 18.5 tonnes, leaving a net payload of 25.5 tonnes. This limits the average weight of each loading unit, such as a roll-cage or a pallet. Assuming a double-deck trailer can take 75 roll cages, the average weight of a cage would be restricted to 340kg. If the same trailer took 54 Euro pallets, the average pallet weight would be limited to 472kg. Consequently, double-deck distribution is suitable loads within certain weight ranges. Retail goods distribution often falls within the efficient range for double-deck trailers; however much will depend on the characteristics of the products carried.

Utilisation of double-deck trailers

No data is available on the number of double-deck trailers currently running on UK roads, as it is not required to register trailers in the UK. However, estimates by trailer manufacturers suggest that there are between 7000 to 9000 units currently in use in the UK and this number is growing. Evidence of this growth of double-deck trailer use is provided by the Continuous Survey of Road Goods Transport (CSRGT 2010). Since 2004 CSRGT has asked respondents to identify double-deck trailer operations separately. The resultant statistics show a steady rise in terms of total mileage, total km driven and the total weight of goods lifted (Fig. 1).

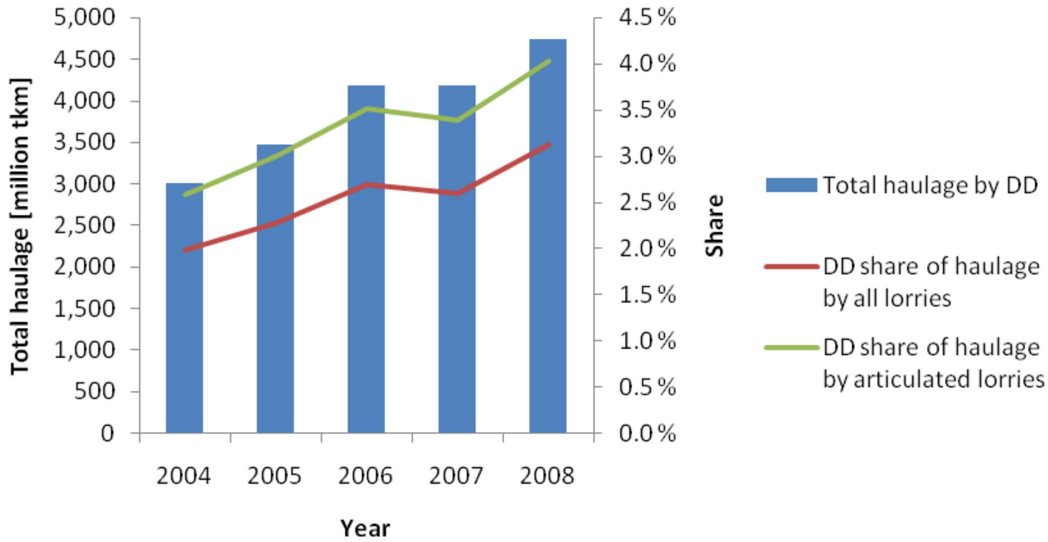

Figure 1. Total haulage by double-deck trailers and its share of haulage by all lorries and articulated lorries

CSRGT respondents are also asked whether the loading is constrained by weight, volume or both. 19% of tonne kilometres moved by double-deck trailers are constrained by weight compared with 39% for all articulated lorries. The share of tonne kilometres constrained by volume is lower for double-deck trailers (62%) than it is for all articulated vehicles (69%). On the other hand, the share of empty running for double-decks is 20% of total mileage, compared to 27% for all articulated lorries. This suggests that double-deck trailers are used on routes with a higher probability of backloading, ensuring that the more expensive double-deck trailer is intensively used. The average length of haul for double-deck trailers (160 km) is also significantly longer than for all articulated lorries (123 km), confirming their role as an essentially long-haul truck vehicle.

Environmental benefit of double-deck distribution

Most of the environmental benefit of double-decking trailers accrues from the reduced energy consumption per tonne-km. There is very limited data on the fuel consumption of double-deck trailers, especially compared with that of single-deck trailers. Double-deck trailers are taller than standard single-decks and hence generally have a higher drag coefficient. According to aerodynamic tests by MIRA, increasing trailer height from 4500 mm to 4875mm increases fuel consumption by 2.4 % while the difference between 4000mm and 4875mm trailers is a 5-6 % increase in fuel (Lawrence David 2004).

Aerodynamic profiling of a double-deck trailer and adding an air kit to the tractor unit can save 5-10 % fuel compared with a standard double-deck combination (Coyle 2004; Malviya et al. 2008; Department for Transport 2006; Lawrence David 2004; Trailers Resources 2008; Commercial Motor 2008). Thus, the difference in fuel consumption between a standard single-deck trailer and an aerodynamically profiled double-deck trailer is likely to be quite small. However, double-deck trailers are heavier than single-deck trailers and this is especially the case with double-deck trailers with a hydraulically powered upper deck. According to Coyle (2007), every one ton increase in weight increases fuel consumption by around 0.5 l/100km. With a potential difference in tare weight of 8 tons between single-deck and powered double-deck trailers, this would mean a 4 l/100km increase in fuel consumption if the payload remained the same. With the increased capacity and thus increased payload, the difference can be even greater than this. Tests by Somerfield indicated an average consumption of 29.4 l/100km for single-deck trailers on UK trunk trips, but a change to double-deck trailers increased the fuel consumption to 35.1 l/100km and using aerodynamic profiling brought the fuel consumption of double-decks back down to 32.6 l/100km (Department for Transport 2006).

The higher fuel consumption, however, much be related to the greater carry capacity. In terms of fuel consumption per tonne kms or pallet-km, double-deck vehicles are much more energy efficient than single-decks. The following example (Table 1) illustrates the fuel reduction benefits of double-deck trailers.

	Single-deck	**Powered double-deck**	**Difference**
Payload (number of pallets)	35	52	49 %
Avg. weight (tonne/pallet)	0.3	0.3	0 %
Distance (km)	200	200	0 %
Tare weight (tonnes)	14	22	57 %
Payload (tonnes)	10.5	15.6	49 %
Total haulage (tonne kms)	2100	3120	49 %
Average consumption (l/100km)	30.2	37.9	26 %
Total consumption (litres)	60	76	26 %
Fuel intensity (litres/pallet)	1.73	1.46	-15 %
Fuel intensity (litres/tonne kms)	0.029	0.024	-15 %

Table 1. Comparison of fuel efficiency between single-deck and double-deck trailers.

The above example illustrates a situation where single- and double-deck trailers move the same distance, both fully loaded with pallets of the same average weight. Even though the average and total fuel consumption are higher for the double-deck operation, the energy intensity is much lower. Furthermore, if the single-deck was used to carry 52 pallets, an additional trip with 17 pallets would be necessary. This would raise the total fuel consumption to 115 litres and the fuel intensity to 2.21 litres/pallet or 0.037 litres/tonne km. Thus, the double-deck operation would reduce fuel consumption by a third. The difference is even greater if the different levels of empty running achieved by double and single-deck vehicles are taken into account.

The fuel consumption used in this example is calculated using our estimation on the relationship between weight and fuel consumption. This relationship is estimated to be [Fuel Consumption = 0.523 * total weight + 17.386] based on test data provided by Coyle (2004). The formula has been modified to suit a double-deck trailer by increasing the constant by 5 % to 18.255 to compensate for increased aerodynamic drag (based on Lawrence David 2004).

Types of double-deck trailers

There is a multitude of double-deck trailer designs (Cartwright Group 2010). This study only considers box vans which are particularly suited for secondary retail distribution, i.e. from the distribution centre to the retail outlets. Three double-deck designs are considered in this model:

- Moving (hydraulically powered) deck.
- Fixed deck with external lift at loading and unloading premises.
- Fixed deck with tail lift.

Fixed deck trailers are suitable for distribution between the distribution centre and larger retail outlets. Both the distribution centre and the outlet need an external lift installed at their premises resulting in very fast and efficient loading and unloading. A fixed deck trailer typically has the highest carrying capacity of the designs considered, both in terms of weight and volume. However, the use of an external lift means that the trailer is less flexible; it can only deliver to stores which are equipped with lifts. While the trailers are relatively inexpensive, the lifts represent a substantial investment.

Moving deck trailers are more flexible than fixed deck as external lifts are not required. Instead, the entire upper deck can be raised or lowered during loading and unloading. Power decks are suitable for distribution to most stores that can accept a 6-axle articulated vehicle. Power decks, however, are very expensive. A high specification power deck can cost around £70,000 compared with a fixed deck at £25,000. Secondly, a power deck is generally heavier than a fixed deck, owing to the internal lifting hydraulics. This restricts the power deck to carrying only very light goods. As the trailer is heavier, there is also a fuel penalty associated with power decks, estimated to be approximately 10% relative to a fixed deck trailer.

The fixed deck with tail lift represents a compromise between the latter two designs. The upper deck is fixed, but no external lift is required, making the trailer more flexible. The weight penalty is low and volume capacity is not sacrificed to accommodate the lift internally. The drawback is that unloading is slow. The tail lift has limited capacity and requires multiple movements to unload a full deck. A fixed deck with tail lift is ideal for multi-drop routes where the unloading time is low compared to the driving time.

Methodology

The model was developed through a series of case studies. Data was collected from three double-deck trailer manufacturers, one manufacturer of unloading equipment and two 3PLs. The case studies provided quantitative and qualitative data required to develop the cost model. The model was further validated by comparing the findings with the CSRGT data for double-deck vehicles in the UK. CO2 emissions are calculated using established methodologies (e.g. Piecyk, 2010) and incorporated into the model.

The model relies on three parameters. First, user data, which are input values corresponding to the user's fleet size, total distance travelled, etc. These values effectively act as cost drivers, determining the total distribution cost for the different vehicle scenarios.

Second, the model contains advised values which have been derived from the case studies. These include the purchase cost and the depreciation for trailers, labour cost and other figures which were found to be representative of a distribution operation in the UK. As the model is based on a limited number of case studies, these advised values are not intended to be representative of all distribution operations. The model allows the user to override these values where more company-specific information is available.

Third, the relationships between the cost drivers and the advised values were based on reports in the literature and later validated by the case studies. Further validation is required through additional case studies. The user data, advised values and relationships are shown in Tables 2 and 3 below.

Cost model application

There are three steps in applying the model. First, user input data may be obtained from the application of routing and scheduling software (such as Paragon, Optrak, etc). A set of routes currently operated by single-deck trailers should be modelled with relaxed capacity constraints, for example by increasing the trailer capacity by 60%. The new routing with increased capacity simulates the effect of using double-deck trailers. The routing software informs the user how many trailers are required, journeys per month and other critical data.

Secondly, the original single-deck data should be input into the cost model along with their new double-deck counterparts. In addition to the conventional single-deck trailer, there are three double-deck scenarios: Power deck, fixed deck using external lift and fixed deck using a tail lift. The capacity of each vehicle type will vary, so vehicle routing should be performed with varying carrying capacities. Table 2 shows the user data and the advised values.

Parameters		Fixed deck trailer	Full power deck	Fixed w tail lift (int/ext)	Single-deck trailer
User data	Number of trailers	10	10	15	20
	Number of journeys/month	600	600	600	900
	Avg kms per journey	80	80	80	60
	Total driver hours/month	3,200	3,200	4,000	6,000
	# lifts at distribution centre	2	n/a	n/a	n/a
	# drop locations with lifts	5	n/a	n/a	n/a
	Avg weight per loaded unit (kg)	200	200	200	200
	Units to distribute/month	29,000	29,000	29,000	29,000
Advised values	Trailer capacity	52	52	50	35
	Trailer and tractor tare weight (kgs)	18,500	22,500	20,000	14,000
	Tractor variable cost per km	£0.06	£0.06	£0.06	£0.06
	Trailer variable cost per km	£0.03	£0.05	£0.05	£0.03
	Trailer purchase cost	£25,000	£55,000	£35,000	£15,000
	Trailer economical life span (years)	10	7	8	15
	Trailer maintenance per year	£260	£650	£650	£200
	Driver labour cost / hour	£10.10	£10.10	£10.10	£10.10
	Diesel per litre	£1.17	£1.17	£1.17	£1.17
	Loading time per unit (min)	1.00	0.75	1.6	0.75
	Unloading time per unit (min)	1.00	0.75	1.6	0.75
	Loading/unloading labour cost / hour	£8.32	£8.32	£8.32	£8.32
	DC lift purchase cost	£140,000	n/a	n/a	n/a
	Store lift purchase cost	£70,000	n/a	n/a	n/a
	Lift economical life span (years)	12	n/a	n/a	n/a
	Lift maintenance per year	£600	n/a	n/a	n/a

Table 2: User data which act as cost drivers for the model and advised values (shaded area) which were found through case studies

Based on the user data (from vehicle routing software) and advised values (provided by the model), the model produces cost and carbon footprint data for each scenario. The results are calculated on the basis of certain relationships between user data and advised values which are listed in Table 3.

Investment		
	Trailer	# trailers * purchase cost
	Lift - store	# store lifts * purchase cost
	Lift - DC	# DC lifts * purchase cost
Depreciation		
	Trailer	cost / life span * # trailers
	Lift - store	cost / life span * # lifts at drop locations
	Lift - DC	cost / life span * # lifts at DC
Maintenance		
	Trailer	maintenance per year * # trailers
	Lift	maintenance per year * # lift
Loading cost		
		(units to dist * load time + units to dist * unload time) * (labour per hour / 60) * 12
Fuel		
	Cost	# journeys per month * average km per journey * fuel per km * £ diesel *12
	CO2	# journeys per month * average km per journey * kg CO2 per km * 12
Tractor/trailer operational cost		
	Labour	driver hours * hourly driver pay * 12
	Mileage cost	average km per journey * # journeys * tractor + trailer variable cost per km *12

Table 3: Relationships between variables

The third step involves obtaining more accurate information once a general scenario has been chosen. For example, if fixed double-deck trailers were chosen, the user would need to contact trailer manufacturers for specific designs, carrying capacities and cost. Based on this information, the user might consider re-applying the model with more accurate information. Thus the decision-making process becomes an iterative process. The model produces a summary of each scenario as illustrated in Table 4.

Summary	**Fixed deck trailer**	**Full power deck**	**Fixed w tail lift (int/ext)**	**Single-deck trailer**
Carbon emitted (kg) per year	**501,616**	**548,870**	**524,180**	**513,325**
Fixed cost per year				
Depreciation	£77,500	£78,571	£65,625	£20,000
Maintenance	£6,800	£6,500	£9,750	£4,000
Variable cost per year				
Loading cost	£96,512	£72,384	£154,419	£72,384
Fuel	£223,152	£244,174	£233,190	£228,361
Trailer/tractor operational cost	£439,032	£450,846	£547,806	£784,791
Total cost per year	**£842,996**	**£852,475**	**£1,010,790**	**£1,109,536**
Cost per cage/pallet	**£2.42**	**£2.45**	**£2.90**	**£3.19**
Fuel cost per cage/pallet	**£0.64**	**£0.70**	**£0.67**	**£0.66**
Carbon emitted per cage/pallet (kg)	**1.44**	**1.58**	**1.51**	**1.48**

Table 4: Modelled results for each scenario

Conclusion

Double-deck distribution offers substantial financial and environmental benefit. Double-deck trailers could be a key contributor towards the UK's commitment to reducing CO_2 emissions.

This paper introduced a model that calculates the financial and environmental impact of introducing double-deck trailers on a specific set of routes. Three scenarios are examined: Fixed deck, fixed deck with tail lift and moving double-deck. These scenarios were also compared to the use of standard single-deck trailer.

Based on industry case studies a model is developed which captures the cost drivers of each scenario. The study is the first to quantify the comparative benefits of using fixed deck or moving deck trailers from a financial point of view as well as considering CO_2 emissions. The study confirms previous research highlighting the benefits of using double-deck as opposed to traditional single-deck distribution.

For a given set of routes, the practitioner can easily compare the three scenarios, finding the most cost effective and most environmentally-friendly option. Existing double-deck users can benchmark their operation using the model. The model is flexible enough to allow comparison of a wide range of distribution networks and routes.

Further research includes additional case studies to pilot and the model. The model has the potential to become a useful decision support tool in the UK freight industry.

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