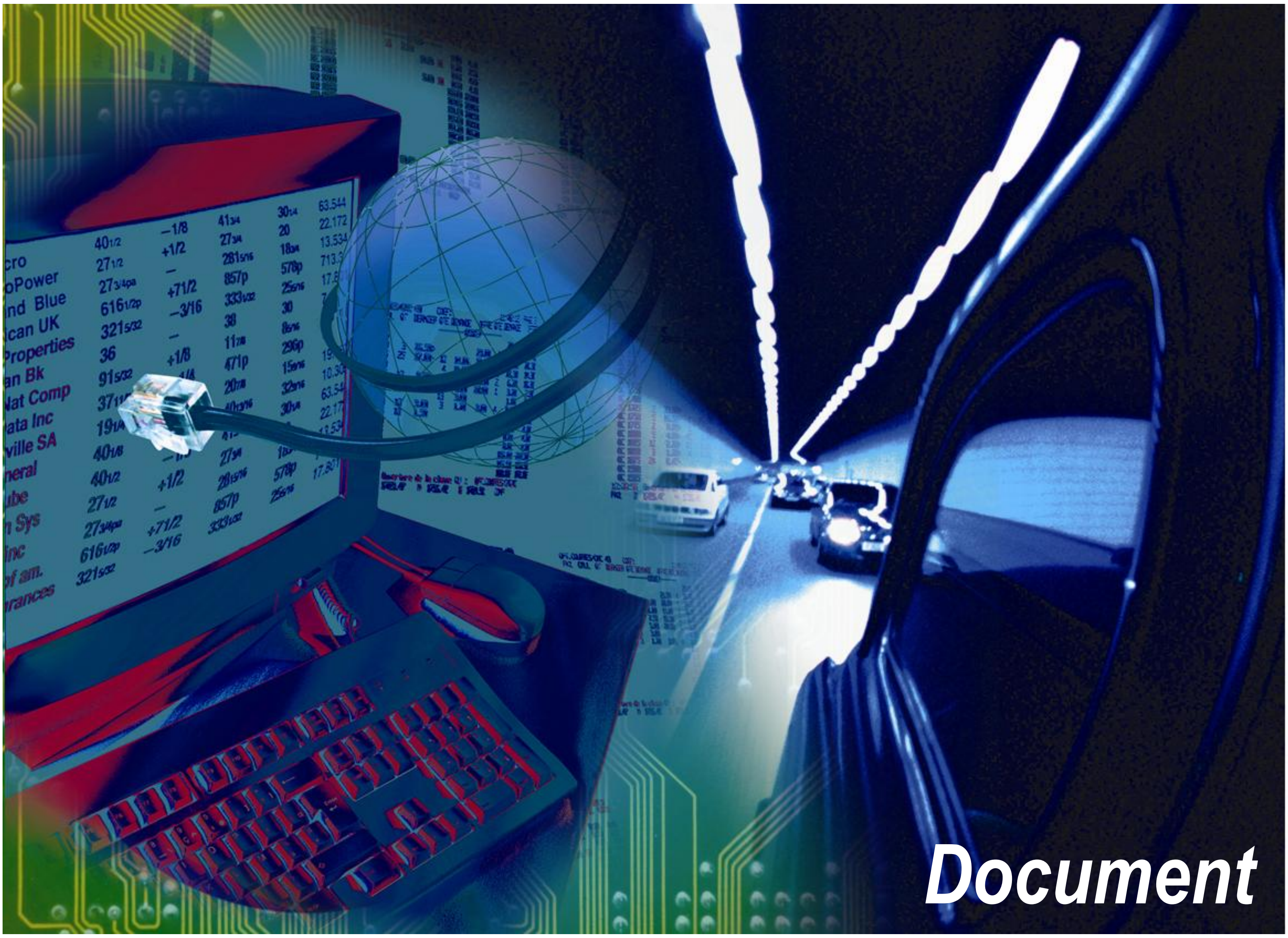
International Transport Forum

Instituto da Mobilidade e dos Transportes Terrestres, I.P.

Innovation in Road Transport

Opportunities for Improving Efficiency

Seminar • 2 October 2009 • Lisbon, Portugal



INNOVATION IN ROAD FREIGHT TRANSPORT ACHIEVEMENTS AND CHALLENGES

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Innovation in Road Freight Transport: Achievements and Challenges

Paper prepared for the International Transport Forum / IMTT Seminar on
'Innovation in Road Transport: Opportunities for Improving Efficiency'

Lisbon

2nd October 2009

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1. Introduction

The road freight sector has traditionally been a fertile area for technical and managerial innovation. Companies in this sector are under strong economic, environmental and social pressures to upgrade their operations, making them receptive to new ideas. Few industries are so intensively competitive, have such a wide environmental exposure and impose such demanding social conditions on their work-force. Partly through the adoption of innovation, the haulage industry has an impressive record of achievement across the so-called 'triple bottom line'. In the UK, for example, truck productivity (expressed as tonne-kms per vehicle per annum) has increased five-fold over the past 50 years, average emissions of NOx and PM10s per tonne-km dropped by around 70% between 1990 and 2007, while in-cab conditions for drivers and health and safety standards have greatly improved.

Despite these achievements, however, the diffusion rate for some innovations has been relatively slow. For example, the switch to curtain-sided trailers, adoption of the digital tachograph, installation of vehicle tracking systems and application of fuel economy measures could have occurred much more rapidly. There is evidence too that when new equipment and systems are acquired, hauliers often fail to exploit their full potential. The reluctance to innovate and the failure to maximise the benefits of innovation can be attributed to a range of factors, some internal to haulage businesses, others externally controlled.

This paper begins by asking what is currently driving innovation in the road freight sector. It then presents a classification of innovations in this sector and provides brief reviews of the main innovative developments currently affecting the movement of freight by road and / or likely to exert a strong influence in the future. Later sections examine the factors inhibiting the diffusion of innovation in the trucking industry and the role of public policy in overcoming barriers to implementation and incentivising the uptake of innovations likely to yield wider benefits for the economy, environment and community.

2. Drivers of Innovation in the Road Freight Sector

Broadly speaking, innovation is driven by the desire to improve the 'triple bottom line', to secure direct economic, environmental and social benefits, but also to enhance the trade-offs that are made between these three dimensions of sustainability. The dominant driver is unquestionably economic and is likely to remain so, though, greater weight is being attached environmental and social objectives. Many trucking innovations yield a combination of economic, environmental and social benefits, strengthening the operator's financial position, improving working conditions and yielding wider environmental benefits to the community at large. Most originate in and are fully funded by the private sector, though public agencies also have a strong interest in the deployment of new technology in road haulage in the pursuit of a range of transport policy objectives.

2.1 Economic drivers:
Road freight innovation can benefit on both sides of the company balance sheet. It can raise productivity, cutting operating costs per tonne-km, while improving the quality of service to customers, can often, though regrettably not always, translate into higher revenue.

Productivity: Given the high energy-intensity of road transport and near-total dependence on fossil fuels, much innovation has been targeted on fuel economy. Up to the early 1990s, truck manufacturers managed to raise the average fuel efficiency of new trucks by around 0.8-1% per annum (International Energy Agency, 2007). Since then the main R&D effort has been on maintaining fuel efficiency, or minimising the loss of fuel efficiency, while meeting tightening controls on noxious emissions. With fuel accounting for 25-30% of haulier's total costs and their profitability highly sensitive to fluctuating oil prices, the pressure improve energy efficiency will remain intense. The productivity of road freight operations can also be raised in many other ways, including increasing carrying capacity, improving load planning, accelerating loading and off-loading operations and optimising routing and scheduling.

Service quality: the main service criteria are speed, reliability, visibility and security. Opportunities for increasing truck speeds are clearly constrained by speed limits and traffic conditions, though door-to-door transit times can still be reduced by better vehicle routing. Improved maintenance regimes and telematics can minimise deviations from schedule, while a range of technologies can be used to offer customers a track-and-trace service for road consignments. A combination of on-vehicle controls and tracking devices can greatly reduce the risk of these consignments being lost or stolen while in transit.

***2.2 Environmental drivers*:**
Tightening controls on exhaust emissions have been the main environmental driver. Regulation has also been used to promote the introduction of quieter vehicles, though some companies have beyond legal requirements and introduced additional noise abatement devices and measures (such as air brake silencers, internal load restraint systems, low rolling resistance tyres, quieter refrigeration units and cab sound-proofing), mainly to gain permission to deliver in sensitive neighbourhoods during the evening or night. Another road freight externality that has been reduced by technical innovation is vibration, which can be damaging to both to road infrastructure and road–side properties. Widespread adoption of 'road-friendly' air-suspension, again enforced by regulation, has substantially eased the vibration problem. With the exception of night-time running, little economic benefit has accrued to operators or their customer from these environmental innovations, hence the need for regulatory enforcement.

***2.3 Social drivers*:**
Regulation has also played a key role in raising safety standards in the road freight sector both for drivers and other road users. Tachographs, under-run bumpers, anti-spray devices and reversing alerts have all made a valuable contribution to road safety. It is possible, however, for firms again to exceed regulatory requirements and invest in additional safety features. Apart from the corporate social responsibility (CSR) benefits that they can bring, companies adopting safety improvements can be rewarded with lower insurance premiums. In the case of safety-related innovations, however, there can be a time-lag of at least 2-3 years before these discounts are awarded because insurance companies require new systems to be in operation for some time before the risk reductions can be assessed (Young, 2009).

3. Types of Road Freight Innovation

This paper takes a broad view of road freight innovation in several respects. First, it does not simply focus on the vehicle. It also includes the design of handling systems and external loading devices that influence the efficiency with which the vehicle is used. At a higher level, it looks at the management of fleets of vehicles and the road networks on which the vehicles travel. It is possible to extend the scope even further to include the management of the logistical system through which the freight flows. Second, innovations can comprise technical improvements to hardware, the development of new software and application of new management principles. Some innovations, such as telematics, embrace all three. Third, how radical must a change be to be designated an ‘innovation’. Must it be pioneering and offer a step-change improvement or do incremental improvements qualify? Tidd et al. (2001) differentiates four levels of innovation in terms of its impact on competitiveness ranging from ‘continuous incremental’ through ‘complex’ and ‘radical’ to ‘disruptive’ which essentially creates a ‘new value proposition’. In this paper, a broad definition of innovation is adopted which subsumes all these categories.

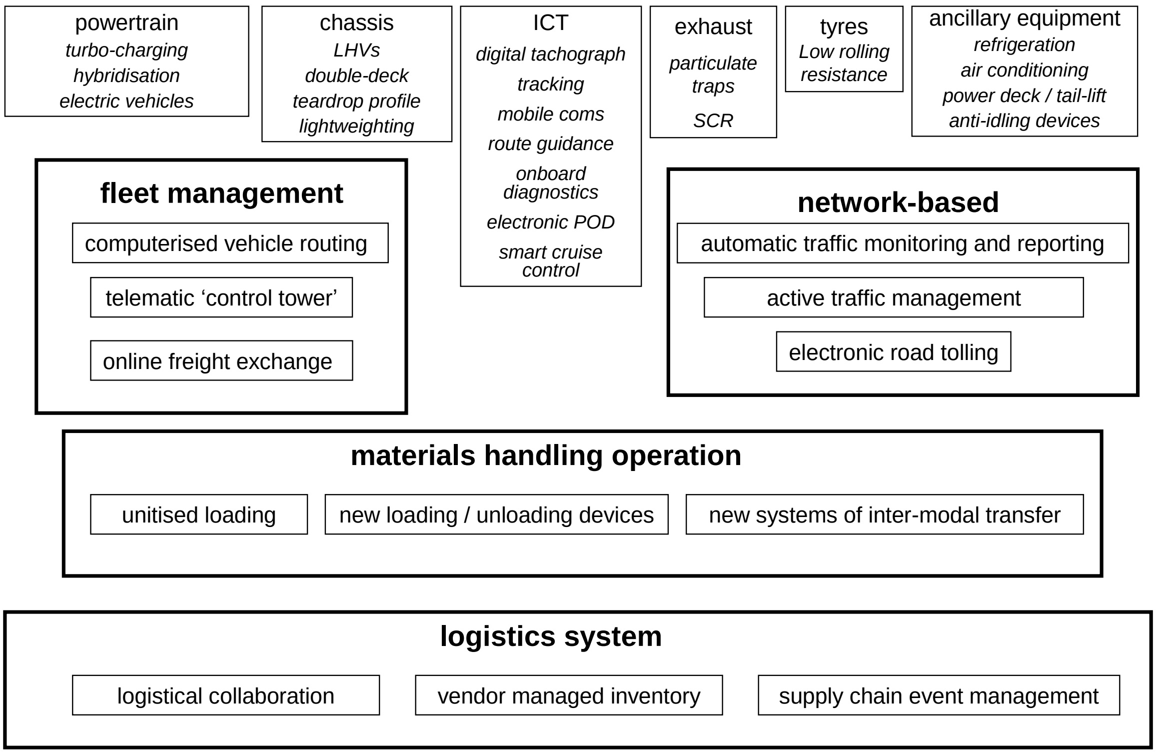
Figure 1 classifies road freight-related innovations into five categories:

1. On-vehicle: *relating to the design and equipping of the truck*
2. Fleet management: *the external planning and control of fleets of trucks*
3. Network-based: *relating to the management of road infrastructure*
4. Materials handling operations: *which affect the loading and unloading of vehicles and nature of the handling equipment used (e.g. roll cages, stillages)*
5. Logistics systems: *the interface between the road transport operation and other logistical activities such as warehousing and inventory management.*

The on-vehicle category is split into six sub-categories:

a) Power-train: *relating to the engine and transmission system*
b) Chassis: *relating to the shape and carrying capacity of the vehicle body*
c) Exhaust: *filtering and after- treatment of exhaust gases*
d) Tyres:
e) Ancillary equipment: e.g. for refrigeration / air conditioning and raising / lowering loads
f) Information and Communication Technology (ICT)*: the suite of electronic devices on board the vehicle*

Figure 1: Taxonomy of Road Freight Innovations



Within each of these main and sub-categories, examples are given of innovations that have had or are likely to have a significant influence on the efficiency, quality, safety and / or environmental impact of road freight transport. These will be briefly reviewed in the following sections.

3.1 On-vehicle Innovation

Power-train

Research in the US suggests that about two-thirds of future energy efficiency gains in trucks will come from improvements to engine and exhaust systems (National Academies of Science, 2007). Much of the energy saving in conventional diesel engines is likely to come from turbocharging (essentially the recycling of heat in exhaust gases). This allows the downsizing of diesel engines, making it possible to obtain the same power rating with lower fuel consumption. Pressure to decarbonise road freight operations, however, will promote the ‘electrification’ of road transport. The application of hybrid technology: is an important step is an important step in this process. Research by Volvo suggests that combining diesel and battery power could ultimately improve fuel economy by 50%. The limited range and stop-start nature local delivery / collection operations by smaller rigid vehicles make them particularly suited to the use of hybrids. Most of the main European truck manufacturers are currently developing hybrid rigids and they will soon be going into full production. Prototype hydraulic hybrid vehicles, which offer even greater energy and CO_2 savings, are currently being trialled by UPS in the US. Because of the limited range and relatively heavy weight of the battery coupled with the greater fuel efficiency of diesel engines operating at constant speeds over long distances, hybrid technology is likely to have very limited application in long haul operations.

In the longer term, for the road freight sector to achieve the 50-80% cuts in carbon emissions being prescribed for national economies new ways will have to be found for transferring ultra-low carbon electricity generated by renewals, nuclear power and fossil-fuel plants with carbon capture and storage into trucks. It has been suggested that this might entail direct transmission to ‘trolley trucks’ running on an electrified road network. Much more likely is the use of a new generation of high-performance batteries in ‘plug-in’ and fully-electric vehicles. The prospects of hydrogen being used as the medium for transferring low carbon electricity seem limited. As Bossel (2004) has noted, ‘*Renewable energy is better distributed by electrons than by hydrogen*’. While advances in battery technology may permit greater electrification of the long-haul articulated vehicle fleet, the emphasis, for the foreseeable future, is likely to continue to be improving the efficiency of conventional diesel engines with some switch to alternative fuels, such as compressed natural gas, biogas or biodiesel mixes, which can significantly reduce emissions per litre of fuel consumed.

Tightening emission standards have forced vehicle manufacturers to radically redesign truck engines over the past twenty years. Future ‘cleaning’ of diesel engines is likely to be marginal by comparison with what has so far been achieved, particularly if increased priority is given to minimising fuel consumption and CO_2 emissions. Alternative approaches to emission reduction have been adopted by vehicle manufacturers in recent years (Exhaust Gas Recirculation [EGR] and Selective Catalytic Reduction [SCR]). Views differ on which of these systems will offer the more cost-effective means of meeting future emission standards. To comply with the Euro 6 emission standard by 2013, however, it may be necessary to combine the EGR and SCR technologies, particularly if tighter CO_2 emission targets are to be met.

Chassis

The main opportunities for innovation under this heading are to increase carrying capacity, 'lightweight' the vehicle body and improve aerodynamics. The first of these will require some relaxation of vehicle size, and possibly weight, limits. There has been much discussion in Europe (Transport Mobility Leuven et al., 2008) and North America (Transportation Research Board, 2002) in recent years about the costs and benefits of allowing trucks to get longer and heavier, possibly raising the limits to those prevailing in countries such as Sweden and Finland. In countries with generous height clearances, such as the UK and Ireland, operator have gained cubic capacity vertically by using trailers up to 5 metres high. Over the past twenty years in the UK there has been extensive development of double-deck trailer technology, with many different variants produced for particular logistics applications.

The weight carrying capacity of a truck can also be increased by reducing its tare (or empty) weight by, *inter alia*, using less dense materials in truck chasses. According to the European Aluminium Association (2006), switching from steel to aluminium could cut around 3000 kg from the weight of an articulated lorry. This would permit a 11.5% increase in payload of a vehicle registered at a gross weight of 40 tonnes. Research in the US, however, suggests that the fuel savings from reducing tare weight are relatively modest, at roughly 0.5% per 1000lbs (0.45 tonnes) (Southwest Research Institute, 2008; Greszler, 2009).

One of the major challenges for designers will be to maintain or even increase vehicle carrying capacity while improving the aerodynamic profiling of the truck. There is a trade-off between the degree of streamlining and the cubic capacity of the vehicle. The latter can reduce fuel efficiency, expressed on a vehicle-km per litre basis, but the more important energy metric of load-kms per litre is increased. To maintain carrying capacity within a new generation of very low-drag vehicles it will be necessary to extend the legal length limit.

Over-cab spoilers have been the most widely used form of profiling, though it is now recognised that most of the potential fuel savings from improved aerodynamics come from the trailer design. It has recently been recognised that improved profiling of the rear of trailers can also have a significant impact on fuel efficiency. So-called 'teardrop' trailers have begun to appear on UK roads which slope downwards at the front and rear, yielding fuel efficiency gains of up to 10% (Co*mmercial Motor* 8 January 2009). The retrofitting of 'boat-tails' to the rear of US trucks can have a similar effect.

For the foreseeable future, most of the savings from improved streamlining of vehicles are likely to come from wider diffusion of existing technology. In the longer term, however, vehicle manufacturers will adopt radically new truck designs which will yield step-change improvements in energy efficiency. One feature of these designs will be their integration of the tractor and trailer to permit optimal profiling of the complete vehicle and largely eliminate the turbulence created in the gap behind the tractor unit. It is predicted that it will be possible to reduce the coefficient of drag (CD) on articulated trucks from the current average of around 0.57 to values to the 0.30 achieved by some types of car (C*ommercial Motor*, 8 January 2009).

***Exhaust system*:**

The future development of exhaust systems will be intimately related to advances in engine technology. For example, the amount of particulate matter emitted by the engine depends on the temperature and completeness of the combustion process. In the EGR system, combustion temperatures are lower, more particulate matter is emitted and, as a consequence, finer particulate filters must be installed to meet tightening standards on the emission of particular matter. Such filters are not required by SCR systems. The future development of truck exhausts will partly depend therefore on the evolution of EGR and SCR systems, independently or in combination.

Tyres:
The so-called 'next generation' tyres may be able to raise fuel efficiency by 4-8% by reducing 'rolling resistance' on high-speed motorway running. Automatic pressure-monitoring and inflation of tyres will also yield significant fuel savings and improve tyre wear.

Ancillary equipment:
Improving the energy efficiency of auxiliary equipment on the vehicle, such as pumps, fans, air compressor, heating, air conditioning and power steering. The installation of separate power systems for this equipment can also save fuel, as it decouples their operation from that of the main vehicle engine. Separate batteries can be used for this purpose. Substantial fuel efficiency gains can be achieved by overhauling these auxiliary systems. Technology can also be used to correct poor driving practice. For example, anti-idling devices automatically switch off the engine when the vehicle is not moving.

ICT:
This can take various forms, including digital tachographs, now compulsory on new vehicles in many countries, tracking devices, in-cab mobile computing systems and, of course, the driver's mobile phone. The functionality of on-vehicle telematics systems can vary enormously from basic tracking to two-way communication and integration with the vehicle CANbus (Controller Area Network data bus) to permit real-time monitoring of the engine performance and driving style.

The term 'telematics' is now widely used to describe vehicle tracking and communication capabilities. Several user surveys have shown that telematics offers road hauliers a range of benefits. A European survey undertaken in 2002 found that around 84% of hauliers using telematics had managed to improve reliability, 78% enhanced customer service and 60% cut transport costs (Centro Studi sui Sistemi di Trasporto and Cranfield School of Management, 2002). A survey by the UK Freight Transport Association (2005) of member companies using telematics enquired in greater detail about the main benefit they were deriving. This highlighted 'ability to manage vehicles and drivers better', visibility, transit time reductions and control of driver's hours / over-time as the four dominant advantages (Figure 2). The increasing complexity of drivers' hours and working-time restrictions has given road freight operator an added incentive to use telematics for management of staff time.

The emphasis on operational efficiency was reflected in another UK survey of road hauliers using telematics equipment, though this study also found that the ability to verify arrival times at customer premises was also considered an important benefit. Vehicle tracking is also particularly beneficial in the case of hazardous and high-value products. Another use of telematics, explored in detailed by McClelland and McKinnon (, was the automated recording of a range of operational KPIs both to support internal management and permit inter-fleet benchmarking.

Surveys of ICT applications by road hauliers and logistics providers in other countries (e.g. Evangelista in Italy; Pokharel in Singapore and Kilpala et al in Finland) have revealed significant differences in the factors driving ICT adoption, the implementation barriers and declared benefits.

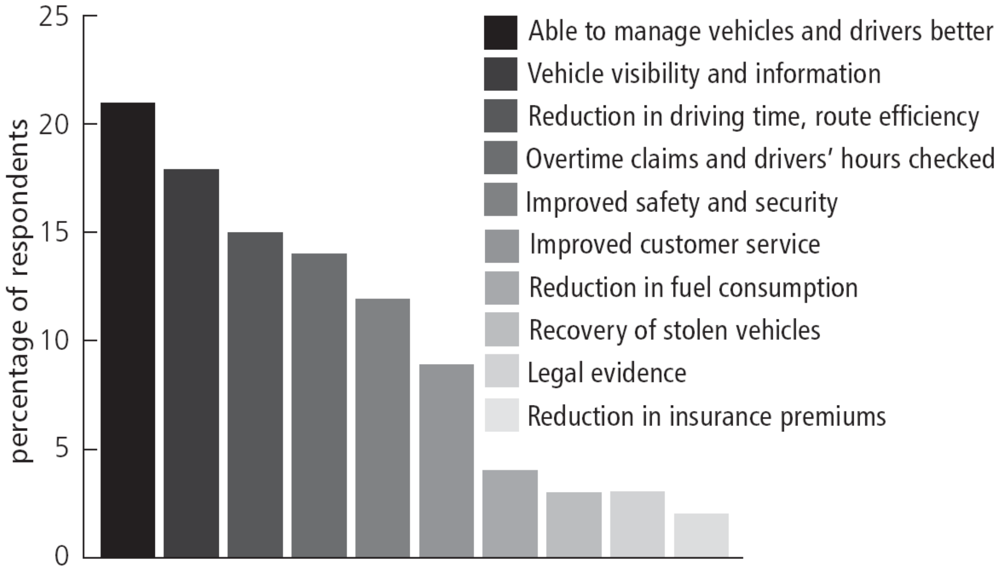


Figure 2: Main Benefit of Telematics to Road Freight Operators.
(source: Freight Transport Association, 2005)

It is important to relate on-vehicle ICT devices to the market for telematics services as this can vary widely from country to country. This can be illustrated by a comparison of the truck telematics markets in the US and UK. One of the major drivers of telematics adoption in the US long haul fleet has been the state-level system of fuel tax reporting, which requires carriers to declare the distance travelled in individual states. The determines the allocation of fuel duty between state tax authorities. Extensive use is now made of GPS tracking, often by quite basic devices, to record and validate this distance data. As there is no similar territorial fuel tax system in Europe, there has been no demand for this particular application of the technology. There is also greater demand for driver communication, internet and entertainment services in US trucks, probably reflecting the greater haul lengths and higher specification of owner-driver vehicles. In the UK there seems to be greater use of telematics systems for the reporting of actual activity against plan and in the two-way exchange of data to improve logistics optimisation.

In countries with high fuel costs, such as the UK, there is greater incentive to use ICT to minimise fuel consumption. This is reflected in the growth of telematics applications linked to the vehicle CANbus to record variations in the level of fuel consumption during the journey. One of the largest telematics suppliers in the UK reports that 2-3 years ago only around one in five new applications had this feature enabled, whereas today it is present in four out of five applications. Although this permits the monitoring of fuel consumption in real-time, most companies using 'driving style monitoring' undertake retrospective analysis of a range of fuel-related parameters. As Clancy (2008) explains 'the CANbus records a rich data stream that includes vehicle speed, odometer reading, engine speed, throttle position, gear selection, braking, engine idling, engagement of cruise control and fuel consumption' (p.24). On the basis of this data, software packages to rate driver's performance on specific journeys can be used as a 'coaching tool'. Experience in the UK suggests that this can lead to fuel savings averaging around 7%.

ICT is also furthering the development of paper-less trading within the road freight industry. Electronic proofs of delivery (PODs) are now the norm in many sectors increasing the integrity of the delivery process, cutting administrative costs and accelerating the billing of customers.

The use of road information systems for route / navigational guidance is now widespread in most developed countries, making it easier for drivers to pinpoint locations and find more efficient routes. Over-reliance on such systems can, nevertheless, result in trucks using inappropriate routes and raises wider issues about the de-skilling of the driver's job.

One of the early expectations of on-vehicle telematics has not yet been fulfilled, however, and is unlikely to materialise as a commercial service in the near future. This is the use of telematics to dynamically re-route vehicles in response varying traffic conditions on the road network. In a study undertaken for the ITF in 2008 on the adaptation of logistics operations to worsening traffic congestion on the UK road network, a sample of 35 logistics managers were asked to what extent they were using telematics to mitigate its effects (McKinnon et al., 2009). While many of the companies surveyed had invested heavily in telematics systems, congestion mitigation had, in most cases, been only a minor consideration and none of the companies had introduced dynamic route guidance systems based on real-time telematic data feeds. Responsibility for routing remained with the drivers though they could use road information systems or mobile phone alerts in deciding whether and how to bypass traffic bottlenecks.

The development of telematics-based dynamic rerouting of trucks has been constrained by several factors. First, there has so far been a lack of demand for this functionality even from companies in areas seriously affected by traffic congestion. Much traffic congestion is, after all, relatively stable and predictable and reasonably easy to factor into delivery schedules. Second, there is currently little inter-connection between road network-based and vehicle-base telematic systems, the former operated by highway authorities and road information companies and the latter by third-party telematics providers and vehicle manufacturers. Third, using real-time traffic flow data to regularly re-optimise a vehicle's movements while on the road would present formidable analytical challenges, particularly if the 'solutions' were to be consistently of a high enough standard to win the driver's confidence.

Another likely development in the field of telematics is the extension of the tracking capability from vehicle to consignment and even product level. The cascading of Radio Frequency Identification (RFID) tags down the unit load hierarchy from containers to pallet-loads to cases and ultimately individual products will make it possible to achieve supply chain visibility at higher levels of resolution. On-vehicle sensors linked to the telematics system could then detect (and even communicate with) individual freight units making it possible to determine the location of any item in transit at any time. This technology currently exists though is not yet sufficiently robust for wide commercial application. Nor is RFID tagging at consignment / product extensive enough as yet to justify it. At present, data on the contents of a vehicle is recorded in electronic manifests at the point of despatch and relayed to the receiving location, sometimes as the vehicle is approaching and crosses a geo-fence at a fixed radius from this location. For some types of distribution operation, such as deliveries to shops, this system may suffice for the foreseeable future. For others, such as parcel delivery, on-board scanning of individual consignments would enhance the track and trace capability and could add value to the logistics service.

Research in Japan is currently exploring the use of RFID tagging to track carbon emissions attributable to particular consignments as they move along the supply chain (Yoshifuji et al, 2008). By linking fuel measurement devices on the truck to onboard transponders, information about fuel consumption and hence CO_2 emissions can be relayed, on a real-time basis, to RFID tags on pallets or cases. By combining this fuel consumption data with information about the loading of the vehicle each consignment can be allocated a share of the CO_2 emissions on each leg of the freight movement. CO_2 data accumulated on the tag during its passage through the supply chain could then be displayed on an end-of-shelf or hand-held reader at the point of sale to inform consumers of the carbon footprint of the product.

Another longer term development might be the implementation of smart cruise control which, in essence, would link telematics to the truck's power-train. It would entail over-riding the driver and adjusting the vehicle's speed and gearing to the topography of the road ahead. While this could improve fuel efficiency it would require acceptance by the driver and reliance on sophisticated technology and up-to-date digital mapping.

3.2 Fleet Management

Computerised vehicle routing and scheduling:

Over the past quarter century, computerised vehicle routing and scheduling (CVRS) software has vastly improved in terms of its functionality, flexibility, applicability, user-friendliness and the efficiency of the solutions it produces. While the quality of the product has dramatically improved, the real cost of the software and associated hardware has sharply declined. CVRS helps companies to optimise the use of vehicle assets with respect to various metrics, including distance travelled, driving time, vehicle loading and cost. Greater weight may be given to energy consumption and CO_2 emissions in the future calibration of these packages. It is difficult to estimate the average gain in transport efficiency from the use of CVRS as this depends on the complexity and variability of the delivery operation and the standard attained by the previous system of manual route and load planning. Transport cost savings of 10-15% are not atypical (Department for Transport, 2005). Efforts are currently be made to incorporate historic telematics data into CVRS systems to replace fixed average speeds for particular road classes with mean values and variances for the speed actually achieved on specific road links at particularly times of the day and week. This is likely to yield more optimal solutions particularly on congested road networks. This integration of telematics and CVRS in the planning of routes prior to the vehicle's departure are a long way from the dynamic rerouting of vehicles on the road described above.

Over the past decade, a new generation of higher level modelling tools has been developed to optimise freight transport networks (rather than the multiple drop delivery rounds to which CVRS packages are normally applied). Particular demand for such packages has come from large retailers that have integrated their systems of primary (factory to DC) and secondary (DC to shop) distribution and are trying to maximise truck utilisation across this entire network. Currently available packages perform reasonably well, though the development of new software tools incorporating genetic algorithms should yield even more efficient solutions.

Telematic 'Control Tower':

Telematics gives fleet managers comparable visibility of their vehicle fleets to an air traffic controller monitoring incoming and outgoing flights at an airport, hence the use of the term 'control tower'. This allows them to reschedule and reroute vehicles in response to changing customer demands, traffic conditions and other random events.

Online Freight Exchange:

Traditionally it has been the role of intermediaries in the freight market, such as freight forwarders and brokers, to act as clearing-houses for information about available loads and vehicles. They relied on market knowledge, personal networking and the telephone to arrange deals between shippers and carriers. With the advent of the internet, a new generation of freight exchanges emerged, providing web-enabled tendering, online auctions and bulletin boards for road haulage services. This has greatly improved the opportunities for matching loads with vehicle capacity, particularly on backhauls. One online freight exchange has estimated that companies using its procurement services have been able to cut their transport costs by 8% by increasing 'carrier's asset utilization while protecting their margins' (Mansell, 2006, p.27). More sophisticated online procurement options are now available involving the bundling of several companies freight demands prior to the auction and the use of algorithms to improve the match between shippers' road freight demands and the available trucking capacity. Web enabled tendering of large shippers' freight demands over periods of 3 -12 months appears to have had a greater impact on the efficiency of road freight operations than short-term load-matching on a day-to-day basis. It has proved difficult for freight exchanges operating in this sector of the online market to generate the critical volume of vehicle movements needed create a healthy supply of backloading opportunities (McKinnon and Ge, 2006). One possible way of reaching this critical mass might be to feed telematics data on the positioning of empty vehicles and available loads into online freight exchanges, essentially merging two technologies, to populate the 'e-marketplace' for road freight with many more potential matches. The Skylark system set up in the UK in 2005 by several large fast-moving consumer goods manufacturers, including Mars and Procter and Gamble, and a group of regional hauliers, attempted something similar within a closed network, though has since been closed down (Anon, 2006). This does not mean, however, that the concept is fundamentally flawed.

3.3 Network-based

Much of the trunk road network in developed countries now has automatic traffic monitoring systems in place using scanning devices, cameras and embedded sensors on the road surface. These monitor all types of traffic and not simply trucks, though in some countries and regions weigh-in-motion sensors have been installed which are specifically targeted on the freight vehicles for the enforcement of over-loading devices and / or weight-based road tolling. More advanced highway authorities are deploying 'active traffic management' using real-time traffic data to manage road space more effectively by, for example, varying speed limits and / or controlling vehicle access to motorways at slip roads.

Currently the most sophisticated application of network-based telematics is in electronic road tolling, with the German Toll-collect system the largest and most complex of its type, deploying a combination of satellite and terrestrial tracking systems to ensure near full compliance across domestic and foreign fleets (McKinnon, 2006a). Concern has, nevertheless, been expressed in Europe that the electronic tolling systems currently in operation (in Switzerland, Germany, Austria, the Czech Republic and Slovakia) and being planned in Europe (e.g. Netherlands) have been customised to national requirements and offer limited inter-operability.

3.4 Materials Handling Operations

The nature of the unitised loading systems and handling equipment used in the road freight sector strongly influences the efficiency with which trucks are used, particularly their loading and turnaround time. Pallets, slip-sheets, roll cases, stillages and dollies, are likely to remain the staple handing devices in the road freight sector, though greater standardisation of their dimensions would improve load compatibility and vehicle utilisation. The growth of reverse logistics has triggered a wave of innovation in the development of new returnable handling items (RTIs) which are replacing one-way packaging and need to be brought back for reloading. Another recent development in the UK has been the transfer of the lifting gear (such as vehicle tail-lifts and the powered-decks on double-deck vehicles) from the vehicle to the reception bays at factories, warehouses and shops, thereby saving several tonnes in vehicle payload and improving the reliability of loading and unloading operations. Under this heading, one can also include the transfer of modular units (such as containers and swap-bodies) between trucks and other transport modes. There has been no shortage of innovative thinking on the subject of road-rail intermodal transfer, to facilitate, accelerate and cheapen this operation and thereby make intermodal services more competitive and more widely accessible.

3.5 Logistics Systems

The logistics systems within which freight moves by road have been transformed by a series of major managerial and technical innovations over the past few decades. Many of these innovations have had a direct bearing on the nature of the transport operation. Some, such as just-in-time replenishment, have resulted in some loss of transport efficiency while others, such as inventory centralisation, are likely to have had the opposite effect by consolidating flows on trunk routes. Three logistics innovations at different stages in their diffusion illustrate the effects on road freight operations:

***Logistical collaboration*:**
Although not a new idea, inter-firm collaboration in logistics has only recently begun to gather momentum and offers the prospect of substantial rationalisation of road freight operations. In the UK, the sharing of transport resources by companies with complementary transport requirements (Kelloggs and Kimberly-Clark) and even direct competitors in the same market (Nestle and United Biscuits) have cut truck distances annually by, respectively, 430,000 km and 280,000 km (Anon, 2008; Hastings and Wright, 2009). Collaborative initiatives of this type can be greatly supported by vehicle telematics, particularly where the participating companies and their logistics service providers operate from a common ICT platform. This makes it much easier to find backloading and load consolidation opportunities and to co-ordinate the activities of the various fleets. Another form of collaboration which benefits from advanced ICT (known as ‘collaborative transportation management’ in the US) includes carriers in a so-called ‘logistics triad’ with producers and retailers across which demand and planning data are shared. This effectively gives carriers an ‘extended planning horizon’ and allows them to increase the utilisation of fleets, by between 10 and 42% according to one US survey (Esper and Williams, 2003).

***Vendor managed inventory*:**
This gives suppliers control over the replenishment process enabling them to phase the movement of products in a way that makes more efficient use of vehicle capacity. Simulation modelling has been used to demonstrate the potential transport benefits of VMI over a ‘traditional supply chain’ (Disney et al, 2003). To maximise these benefits it is often necessary to increase storage capacity at the customer’s premises to accommodate the delivery of supplies in full truck-loads.

***Supply chain event management*:**
This involves decomposing supply chain processes, including road transport, into a series of discrete events, each of which is closely monitored to ensure that they are carried out within tight tolerances. If these tolerances are breached, pre-arranged contingency plans come into effect to try to correct the problem. For example, if a delivery to a factory is delayed, the consignment might switched to an express mode and the production schedule at the factory altered to accommodate the late arrival. A pre-requisite for SCEM is complete visibility of supply chain processes, which in the case of the road transport operation is afforded by telematics. If it can be successfully and cost-effectively implemented, SCEM should improve the efficiency and reliability of supply chains.

4. Barriers to Innovation Diffusion

Research by Piater (1984) provides a useful framework for the analysis of the factors inhibiting the diffusion of innovation in the road freight sector. He distinguished external and internal barriers and subdivided each group into three categories:

Internal: related to (i) resources, (ii) culture / systems and (iii) human resources

External: related to (i) demand, (ii) supply and (iii) environmental factors

Factors inhibiting the spread of road freight innovations will be discussed under these headings.

4.1 Internal factors:

Resource-related: As noted earlier the road haulage industry is composed of a large number of small operators. In European countries, typically 80-90% of carriers have five or fewer vehicles. They operate on relatively slim average profit-margins of 2-3%, often fail properly to depreciate their assets and are particularly sensitive to variations in fuel prices. As they have little profit to reinvest and often have difficulty securing loan capital, most carriers lack the resources to acquire more expensive innovations. Smaller, less prosperous operators, including many owner-drivers, can only afford to buy second-hand vehicles and thus take longer to benefit from vehicle improvements. If they buy new vehicles, they can often only afford models with lower specification and lacking innovative features. During recessions, operators right across the road freight sector typically lengthen the vehicle replacement cycle, effectively slowing the rate of innovation diffusion within the vehicle parc.

Culture / system-related: The prevailing culture in much of the haulage industry is one of 'making ends meet' and basic commercial survival. Managers have little time to explore technical opportunities for business improvement. Their legacy IT systems are also much too primitive to support the installation of new software and electronic devices. Goel (2009) notes that relatively few small haulage business have telematics-enabled IT systems. There has also tended to be a bias in favour hardware purchases, with managers preferring to see an extra vehicle in the yard than to acquire an intangible software package whose contribution to the business can be harder to evaluate.

*Human-resource-related**:*** Management of road haulage businesses often lack the expertise to make innovation-related investment decisions and to implement innovations to best effect. Drivers and staff may also lack the necessary skills and, when innovations are acquired, fail to receive the necessary training in their use.

4.2 External factors:

Demand-related: Many shippers treat road haulage as a basic 'commodity' service to be purchased at minimum cost. By exploiting the intensely competitive conditions in the general haulage market, they obtain rates that contain little premium for innovation. A prevailing view among carriers is that they do not get adequately recompensed for investments made in innovative systems, even those which enhance the quality of service. In the case of higher-level logistics services, providers sometimes argue that contracts are so strictly defined that they are given limited opportunity to be proactive and innovate. Another demand-related factor is uncertainty about the future residual value of vehicles with innovative features. It can be difficult to predict how these features will affect second-hand values 5-10 years in the future, making more risk-averse operators settle for trucks with more basic specifications.

Supply-related: There has been less evidence of problems at the supply end. In most countries, well developed channels exist, in the trade press, exhibitions and direct mail, to publicise new devices and systems and they can usually be supplied in adequate quantities. The 'supply' problem is related more to support with implementation. Carriers are often not given sufficient training and guidance in the use of the innovation and, as a result, fail to maximise the benefits. For example, there have numerous instances of 'over-selling' and 'under-support' in the UK telematics market, leaving hauliers disillusioned with this technology and deterring the subsequent adoption of more sophisticated systems. Several freight / logistics innovations appear to have followed the 'hype cycle' posited by the Gartner Group (2009) to show the course that many new technologies follow (Figure 3). Initial enthusiasm for an innovation can lead to exaggerated claims about its impact. Expectations are then over-inflated up to a point when managers realise that implementation is more difficult and costly than expected and the benefit more modest. Disillusionment can set in with interest in the new technology waning. If, however, it has real value, it can rise up the 'slope of enlightenment' as viable business models evolve and managers learn how to implement it in a way that yield longer term productivity benefits. In Figure 3, several freight-related innovations have been tentatively mapped onto the 'hype-cycle'.

Environment-related: the term 'environment' here subsumes a range of external factors, such as regulatory, infrastructural and fiscal. For example, legal limits on the size and weight of trucks is currently constraining the use of longer and heavier vehicles in many countries. One reason for the rejection of LHVs in these countries is concern about the ability of road infrastructure to accommodate them[1]. The long delay in the introduction of digital tachographs was largely attributable to the elaborate standardisation process involving governments and industry. The development of communication standards for vehicle telematics is also proving to be an equally protracted process. This may be partly due to truck manufacturers promoting their particular telematics systems as valuable 'add-ons' at time of purchase. This can allow them to undertake vehicle diagnostics during the life of the vehicle and offer, on an ongoing basis, a value-adding range of maintenance and support services. It, nevertheless, inhibits the development of an open industry standard which would almost certainly accelerate the diffusion of telematics. Trade bodies representing road freight operators have also argued that the imposition of high taxes on road transport (mainly through fuel duty) restricts the resources available for investment in new technology.

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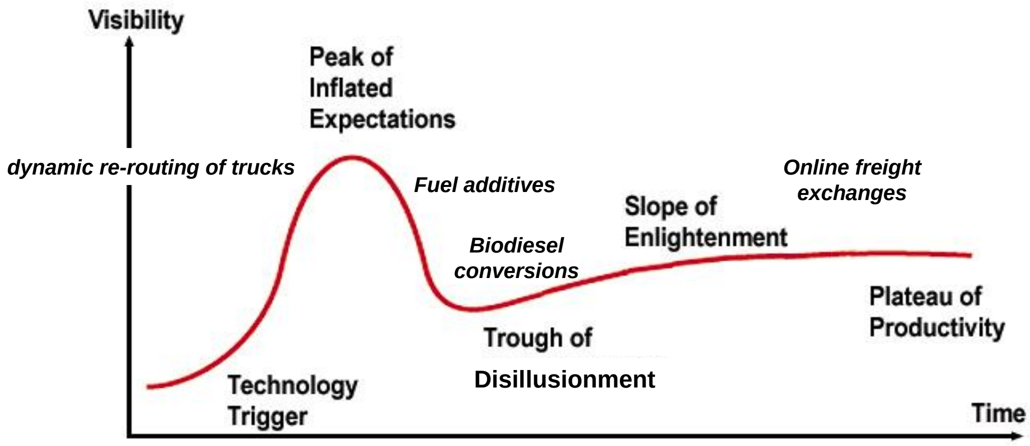
[1] The other major concerns are that LHVs will displace large quantities of freight from alternative, more environmentally-friendly modes, and that road safety will be compromised.

Figure 3: Gartner 'Hype Cycle' for the New Technologies: *Road Freight Examples*



5. Role of Public Intervention in Promoting Road Freight Innovation

To what extent should governments be involved in the development, promotion and implementation road freight innovation? One could advance a *laissez-faire* argument and say that in the case of those innovations that yield economic benefit the free market should provide a sufficient stimulus for R&D and adoption. Why then should public funds be used to subsidise new developments that are likely to be self-financing? The use of public funds to promote the innovation diffusion in the road freight sector can be justified where wider public benefits accrue, such as reductions in emission levels and accident rates. Public intervention can also be justified where there is evidence of market failure retarding the adoption of new technology. It can be argued that in the road haulage industry there may be evidence of such failure in two respects. First, the high degree of fragmentation, intense competition and slim net margins in this industry, make it very difficult for many small operators to raise the initial capital, either from profits or external money markets, to fund the purchase of new devices and systems. Second, owners and managers of road haulage businesses often lack the awareness, knowledge and decision-making skills required to objectively evaluate innovations and recognise their truth worth. Government can therefore play a useful role in trying to correct these two market failures.

The first 'failure' can be addressed by reducing the initial capital outlay on the innovation. This can be one in various ways. One large telematics company in the UK has suggested that trucks equipped with this technology might qualify for a reduced level of annual Vehicle Excise Duty. Alternatively, new devices or services that the government wished to promote could be exempted from VAT / purchase tax. Stronger fiscal support could take the form low interest loans or grants. In the US, for example, as part of the Environmental Protection Agency's SmartWay programme (www.epa.gov/smartway/), road carriers receive assistance in finding suitable finance for the purchase of an approved range of devices and services that reduce the environmental impact of their operations. Clearly any financial support must be structured in a way that minimises market distortion and does not infringe state aid rules.

> Deficiencies in managerial appreciation of technical innovation can be reduced by advisory and exhortation campaigns. The UK government's Freight Best Practice (FBP) progamme provides a good example of such a campaign (www.freightbestpractice.org.uk). A series of user-friendly guidance manuals have been prepared on a range of road freight innovations, mostly relating to energy consumption and vehicle utilisation. Additional advice can be obtained from a telephone helpline. As with commercial advertising it is difficult to measure the impact of such advisory campaigns, particularly as they reinforce the promotional activities of the companies supplying the equipment and services. A market research study has, nevertheless, found that hauliers referring to the FBP literature / advice are significantly more likely to adopt new fuel economy measures (Databuild, 2007). Indeed, at only £8 of government funding per tonne of CO_2 saved per annum, the FBP has been shown to be an extremely cost-effective carbon mitigation initiative.

Some governments are also directly fund R&D efforts in the road freight sector. *The* US Department of Energy, for example, funds fundamental research on the design and testing of more energy efficient trucks and vans. Government-financed research councils also sponsor numerous projects on ways improving the efficiency and reducing the environmental impact of freight transport and logistics operations, many of them with close industry involvement.

These forms of public intervention exemplify the 'carrot' approach. The more *dirigiste* 'stick' approach has also been widely used in the road freight sector to force the pace and direction of technological development. For example, the imposition of Euro standards on truck exhaust emissions, and the equivalent standards in other countries, set vehicle manufacturers clear targets that had to be made by specific dates. In Japan in 2015 truck manufacturers will be required to meet fuel economy standards for new vehicles. The Japanese government's Energy Conservation Law applied the so-called 'top runner' principle to fuel efficiency standards for trucks. This principle aims to make the best-in-class performance the average by a target date. For trucks this will entail improving the average fuel efficiency from 6.30 kms / litre in 2002 to 7.09 kms / litre in 2015 (Ministry of Economy, Trade and Industry, 2008). In this case the 'stick' is accompanied by a 'carrot' as tax incentives are being used to promote this move to higher efficiency standards. The purchase tax is being reduced by 1-2% for new vehicles meeting the target fuel efficiency standards. Both the US government and the European Commission are considering the adoption of fuel economy standards for trucks, though the diversity of vehicles types and the combination of different types of auxiliary equipment on a single vehicle will make this difficult. One can also challenge the likely efficacy of fuel economy standards on two other grounds. First, as competition in the truck market is already aggressive and fuel efficiency is a key purchasing criterion, the <u>incremental</u> benefit of a fuel economy standard will probably be small relative to the technological pressures already exerted on truck manufacturers by market forces. Second, the life-time energy consumption and emissions of a truck are influenced much more its day-to-day operation, loading and maintenance, than by differences in new truck fuel ratings at time of purchase.

Another legislative change likely to stimulate innovation is the requirement of the French government in 2010 that hauliers provide their clients with estimates of the amounts of CO_2 emitted in moving their freight. This will create the need for carbon auditing of road freight operations at a disaggregated level, something that is difficult to provide accurately with given the current ICT capability of many road hauliers.

Governments can use their regulatory powers in other ways to encourage the uptake of road freight innovation. Rather than impose new regulations they can relax existing ones. The easing of constraints on maximum truck weights and dimensions, for example, would permit the development of new forms of longer and heavier truck (LHVs). The need to fit these vehicles into existing road infrastructure and minimise any associated safety risk has led to a series of technical advances in the use, for example, of rear steering axles and new coupling and bogey systems to minimise the vehicle turning circle. Telematics could also be used to confine LHVs to specific networks of higher capacity roads, with linear 'geofences' imposed long approved routes. Drivers straying from these routes would receive warning messages while infringement of routing restrictions would be recorded and penalised.

As illustrated by the case of the Denby 'eco-linker' vehicle in the UK, however, speculative, private-sector development of new LHV technology ahead of any relaxation of vehicle length limits can be risky. The UK government's decision in June 2008 to retain the existing length limit for articulate vehicles effectively denied this 25.25 metre vehicle access to the UK road network. In contrast, past increases in truck weight were not only legalised by the UK government but also supported by substantial investment in bridge-checking and –strengthening (McKinnon, 2005).

Public bodies also have a direct interest in the application of new technology in road freight transport. Automatic vehicle identification (AVI), coupled with road-side sensors, are now widely used in the enforcement of speeding, weight and exhaust emissions controls. Satellite-based and terrestrial telematic systems are also used, individually or in combination, in several central European states for road tolling purposes. When plans were being prepared in the UK for a system of Lorry Road User Charging (LRUC), it was claimed that it would *'help to bring the latest technology into the cabs of the UK's lorries where it can be a valuable aid for the haulage industry, offering fleet management and navigation services'* (McKinnon, 2006b). Given the lack of standardisation in telematics equipment and services, there was no guarantee that the 'on board unit' (OBU) for tolling would have been compatible with all the systems available. Government officials also hinted that the haulage industry might be expected to meet at least some of the high costs of building and operating LRUC. Capturing some of the benefit of telematics in higher toll levels would probably have deterred rather than encouraged the uptake of this technology. In any case, the UK government abandoned its plans for LRUC in July 2005.

6. Conclusions

Road freight transport has benefitted enormously from a diverse range of technical and managerial innovations over the past few decades. The rate at which innovations are arising and being commercialised in this sector shows no signs of slackening. Arguably the most prolific sources of innovation for the foreseeable future are likely to be in the fields of ICT and power-train development. There is also likely to be greater convergence of technologies, reinforcing their combined impact on the efficiency, reliability and greening of road freight transport.

The highly fragmented structure and fragile economics of the road freight industry, however, inhibit the diffusion of innovation. The early adopters of innovation are usually the larger logistics companies, which are better resourced, have managerial teams more receptive to new ideas and are under constant pressure to differentiate themselves. The subsequent spread of innovation across the long tail of small operators can be relatively slow and very sensitive to prevailing economic conditions.

Public agencies can use various financial, advisory and regulatory tools to accelerate the development and application of new technology in this industry, particularly where it yields wider economic, environmental and social benefits. They must, however, exercise caution in assessing its impact because there is often a tendency to exaggerate the benefits and under-estimate the cost and complexity of implementation.

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