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Digital technology in freight

The freight industry handles 1.6 billion tonnes of goods within the UK each year[1] and added £139 billion in value to the economy in 2022.[2] 'Technology and data enabled opportunities' are a priority in the Department for Transport's (DfT) Future of Freight Plan.[3] This POSTnote reviews the digital technologies that support freight transport, considering the benefits and challenges associated with their use.

Overview

- Digital technologies are widely employed to support freight management, goods monitoring, transport and last-mile delivery.
- Technologies being used include automated vehicles, robotics, connected sensors, database technologies and analysis tools.
- Technology is impacting all modes of freight transportation (road, maritime, rail and air), and processing at ports and warehouses.
- These technologies could reduce costs and carbon emissions, while improving the transparency and reliability of supply chains.
- Challenges include lack of communications infrastructure, cybersecurity, social concerns and implementation costs.

Background

Freight refers to the carriage of goods over land, sea and air. Digital technology has supported this since the 1960s when software was introduced to help manage inventory and coordinate transport.[4] Freight has since become increasingly reliant on digital technologies,[5] driven by:

- availability of cheaper and more capable computers;[6,7]
- innovation in sensors, robotics and software tools;[8,9] and,
- wider access to high-capacity data sharing infrastructure.[8,10]

Today, freight businesses depend on a range of technologies, including inventory management software,[11,12] navigation devices[13] and cloud platforms for communication.[14] Remote control and automated systems are used for physically demanding and repetitive tasks.[15–17] Digital technology has also led to broader changes in how the freight system operates (Box 1). Emerging technology could reduce costs and improve supply chain reliability.[5] However, thin margins in the freight sector can limit investment in new infrastructure and skills.[3,18]

In 2023, DfT launched a £7 million Freight Innovation Fund to establish promising technologies.[3,19] In the freight sector, funding for research and development is mostly dedicated to achieving the Government's net zero greenhouse gas emissions target.[20–22] Digital technologies contribute to this,[23,24] and DfT's Decarbonising Transport plan recognises that digital solutions are needed to meet the priority of 'decarbonising how we receive goods'.[25] Freight may also benefit from cross-sector support for digital technology, such as funding to develop artificial intelligence (AI)[26] and connected and autonomous vehicles (CAVs).[27] For example, Innovate UK will have invested £40 million in commercial CAVs by 2025.[28,29]

The freight transport system

The freight sector includes stakeholders involved in goods transport, warehousing and logistics.[18] Usually, goods are moved by private companies known as logistics operators.[18] These enterprises subcontract or invest in vehicles and infrastructure,[30] which vary with mode of transport:

- **Road freight,** usually transported by heavy goods vehicles (HGVs), and smaller trucks and vans (LGVs) for the 'last-mile'.[31–33] Road freight has the greatest connectivity and flexibility. In 2022, 77% of goods were carried by road in the UK (in terms of weight multiplied by distance hauled).[34]
- **Rail freight,** moved by trains that carry containers or bulk goods. Rail is more fuel efficient than road[35] and is well suited to moving large volumes into urban centres.[36] For short distances rail becomes impractical with goods generally being transported by road to their final destination.[36]
- **Maritime freight,** including ferries that can carry lorries, bulk material carriers (e.g. tankers) and container vessels.[37,38] Maritime shipping is a cost-effective option for sending heavy cargo over water.[39] In the UK, by weight 95% of imports and exports were transported by sea in 2020.[34]
- **Aviation freight,** transported either by dedicated cargo aircraft, or within the hold of passenger flights.[3] Aircraft are useful for high-value, time-critical items.[40] By goods value, 40% of all UK trade with non-EU countries is carried by air.[39]

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Box 1: Digital technology enabled trends in freight

E-commerce

The UK is the third largest market for e-commerce, behind China and the US.[41] According to the Office for National Statistics, between 2012-22 online sales increased from 9% to 30% of total sales,[2,42] surging during the Covid-19 pandemic.[43] This changed how goods reach customers,[44] reducing high-street deliveries and increasing the use of home delivery services.[41,45] This has driven demand for warehouses,[46] with the number growing by 88% between 2011-21.[47] Industry stakeholders have highlighted that planning policy makes building new premises difficult.[46] The Government is working with industry to increase the number of warehouses.[3,48]

Expanded logistics services

Digital technology has allowed logistics companies to scale-up and expand the services offered to customers through:

- third-party logistics providers (3PLs), which can provide comprehensive services for goods transportation, warehousing and inventory management;[49,50] and
- '4PL' logistics companies that facilitate end-to-end movement of goods by coordinating multiple 3PLs.[50–53]

When goods are moved using multiple vehicle modes it is known as 'intermodal' or 'multi-modal' transport.[54] Goods are transferred between vehicles at 'transhipment points', such as seaports, airports, rail terminals and warehouses.[55] Couriers are operators who specialise in 'last-mile' delivery, which involves moving goods from a local hub to their final destination.[56] Last-mile is usually the most expensive part of a delivery, sometimes accounting for half of overall costs.[57] It is mostly carried out by LGVs, but increasingly by e-cargo bikes, which it is estimated could replace 14% of vans in parts of London by 2025.[41,58,59]

Freight is reliant on publicly owned infrastructure, with 66% of road freight (by weight-distance) moved on motorways or A roads[60] maintained by National Highways.[61] Rail freight is reliant on Network Rail to maintain tracks and terminals.[35,62]

Digital technologies in freight

The following section outlines key digital technologies being deployed in, or developed for, the freight sector.

Connected and autonomous freight vehicles

Advances in AI, data transfer and sensors are enabling vehicles with remote controlled or autonomous driving features. There are different levels of autonomy in CAVs depending on how much human input is needed.[63–66] A variety of automated driving features are found in freight vehicles.[67] In trucks this includes steering assistance and warnings against route departure.[68] In ships and planes, autopilot functions monitor and counteract environmental conditions to maintain course.[69,70] In trains 'automatic block signalling' helps optimise distances between vehicles sharing a railway (PB 20). Full autonomy is a longer-term goal.[71]

Across all transport modes innovations are enabling freight CAVs with reduced human input, including:

- **Platooning lorries,** a method of driving a group of vehicles together in close convoy.[72] Platoons are connected wirelessly and the lead vehicle controls the speed and braking of following trucks.[73] UK trials currently require drivers in all HGVs and allow for no other tasks while platooning.[74]
- **Driverless freight trains,** which can detect obstacles, stop and start without human intervention.[75,76] UK freight trains still rely on drivers. However, one Australian mining company uses driverless trains guided by lasers, sensors and CCTV.[77]
- **Crewless cargo ships,** where crew removal[78,79] could enable ships with increased cargo capacity.[80] In 2022 the first autonomous container ship was piloted in Norway.[81]
- **Drones,** used for aerial delivery (PN 610). These range from small rotary blade drones that deliver over short distances,[82–84] up to large fixed wing systems able to carry heavier cargo.[85] Since 2020, Royal Mail has been involved in trials using drones to deliver packages to remote locations.[86–88]
- **Delivery robots,** which come in a range of sizes are being tested in buildings and in urban areas.[89–93] For example, wheeled delivery robots that travel on pavements are being trialled in Cambridge, Milton Keynes and Northampton.[94–96]

Physical automation at transhipment points

Transhipment points can be well suited to automation when cargo is moved in standardised forms (such as shipping containers) with predictable motions.[67,97,98] Container ports use driverless cranes and CAVs to improve speed and safety.[97,99] The UK's largest automated port is London Gateway, where automated cranes enable truck turn-around times of under 35 minutes and improved port resilience to adverse weather.[100]

Warehouses that deliver a single service or product type are well suited to automation.[9] End-to-end systems include HGV unloaders/loaders,[101] package scanning drones,[102] automatic retrieval shelving and picking robots.[9,17] The UK is predicted to become the largest warehouse automation market in Europe by 2025.[103] Amazon is the UK's biggest investor and uses inventory moving robots at sites in Dunstable, Doncaster and Tilbury.[104]

Internet of things (IoT) and connected devices

IoT devices (PN 593) can be integrated into roads, containers and vehicles to support monitoring of freight services.[5,105,106] IoT devices are fitted with sensors that collect and report information automatically. For example, if integrated into packaging material they can report if goods have been damaged or tampered with by detecting unexpected deviations in temperature, light or humidity.[106,107] Internet-connected user devices also support operations in freight. For instance, smart lockers, accessible by a user who has a digital key, provide pick-up and drop-off points for goods.[108] Also, vehicle drivers use smartphones to communicate with customers and satellite navigation systems such as GPS.[109]

Data storage and management technologies

Collaborative databases provide a repository that relevant parties can access simultaneously, such as customers, shippers and logistics operators. This is often underpinned by cloud computing (PN 629), which uses remote computers to store and process data.[110] For example, Port Community Systems help manage inventory information shared between public and private sector stakeholders within a port or airport.[111–113] Freight is also increasingly supported by distributed ledger technology (DLT) (PB 28), which can improve security by storing data on a shared network of computers.[114] These databases are being used to host data from IoT devices,[115] customs information[116] and digital trade documents (Box 2).[117]

Box 2: Digital trade documents
Moving freight generates documents representing legal and commercial obligations. One example is the bill of lading (BoL), which acknowledges the receipt of cargo and can provide rights to goods described in the document.[117] The Digital Container Shipping Association (DCSA) estimated 16 million BoLs were issued in 2020.[118] DLT and cloud databases can provide a platform to host electronic documents and enable automation of some processes.[119] This could improve security and processing time, while eliminating the cost of generating and storing paper copies. DCSA estimated 50% adoption of electronic BoLs would save shippers $4 billion annualy.[118] In 2022 the Government introduced the Electronic Trade Documents Bill (HL Bill 57), proposing electronic trade documents be legally recognised under certain criteria.[117]

Data analytics and AI

Advances in machine learning (PN 633) have enabled better data analysis tools for freight operations. Some companies use weather forecasting tools supported by AI to optimise journeys, avoid delays and improve safety (PN 628).[120–122] Data from sensors can also be fed into a 'digital twin' of a freight asset (PN 656), which can be used in simulations to optimise the asset's use.[123] This has supported systems that manage warehouse inventory,[124–126] decarbonise transport,[127] and predict maintenance for vehicles,[123,128] railways[129] and roads.[130]

Potential benefits

Digital technologies can improve the cost, reliability and sustainability of freight.[5,67] Key examples are described below.

Addressing labour shortages and cost

The freight and logistics industry employs 2 million people in the UK across 226,000 companies.[131] There is currently an industry-wide labour shortage and recruiting is a challenge, particularly for HGV drivers (LIF HGV driver shortage).[132] There are also shortages in warehouse staff, in part due to unsociable hours and physically demanding labour.[133,134] Automation could help alleviate the labour shortage, with analysis by the Institute for Public Policy Research estimating that 57% of jobs in transport and storage have a high potential for automation.[135] This included manual stock movers, HGV drivers, and truck or ship loaders.[136] However, some experts have called for socially equitable strategies where labour is being replaced.[67,135]

According to a 2019 review commissioned by the National Infrastructure Commission (NIC), the implementation of end-to-end automation in warehouses and driverless road freight could save the UK freight system £26 billion through reduced labour costs.[137] Only 5% of US warehouses have end-to-end automation,[137] but Amazon has reduced operating costs by 20% by deploying robots in 20 warehouses.[138,139] Driverless CAVs for road freight are not yet in use, but potential labour cost savings are estimated to be between 25-30%.[137,140,141]

Reducing congestion and emissions

Congestion is estimated to cost the UK freight sector £3-6 billion per year.[137] Digital solutions are used to reduce the number of road vehicles and the distances they travel.[33,41,142] For example, trials by logistics company DHL found vehicles responding to real-time traffic and GPS data were able to reduced their miles travelled by 15%.[143] Collaborative databases known as 'freight exchanges' improve efficiency by allowing carriers to advertise excess loads and available cargo capacity.[14,144] One exchange, Returnloads.net, estimates its service saves 250 million vehicle miles annually in the UK.[145–147] Furthermore, DfT is undertaking a project evaluating digital 'kerbside management'.[148] One such system piloted by the London Borough of Southwark enabled drivers to book virtual loading bays, reducing time waiting for parking and carbon emissions by around 4.6%.[149–151]

Goods consolidation can also reduce the number of freight vehicles. 'Urban consolidation centres' use software to coordinate vehicles traveling into populated centres, ensuring they have high-loads and optimised route efficiency.[33,142,152] Smart lockers provide consolidated drop-off locations and prevent the need for redelivery of missed goods.[142,153] This is being explored in Salford and London, where local authorities are working with private enterprises to decarbonise freight.[25,153] Plans to install lockers within 250 meters of all London residents could reduce annual delivery miles by 75 million.[154,155]

Accessible and transparent goods information

Digital tools such as cloud computing, DLT, and IoT devices can help improve trust between stakeholders by providing assurance that goods are authentic[156] and transported competently.[157] Sensors do this by automatically uploading the status of goods to a database visible to all stakeholders. For example, software can report if perishable foods and medicines have reached temperatures that could impact their safety.[157,158] Sensors can also help ensure compliance with the law. For example, it has been a legal requirement since 2019 for HGVs in the UK to be fitted with a 'smart tachograph',[159] which ensures drivers don't exceed legal driving time limits.[159,160]

Reduced trade friction

In 2021 the Government committed £180 million to a UK Single Trade Window (STW), which will facilitate better sharing of data among border authorities and act as a single digital entry point for traders.[161,162] STW implementation in New Zealand halved the time shippers spent reporting goods and time Government spent issuing export refunds.[162] Use of digital documents also reduces manual administration and speeds up trade processes (Box 2).[163] In a 2021 survey by the International Chamber of Commerce, small-medium sized exporters estimated that document digitalisation would increase trade by 25%, which could add £25 billion to the UK economy by 2024.[163,164]

Potential challenges

This section describes challenges raised by the implementation of digital technology in freight and steps taken to address them.

Technical challenges

Communications infrastructure

Many digital technologies depend on high-speed data sharing infrastructure, such as 5G mobile (PB 32) and fibre-optic networks.[165] This is needed to support IoT devices that monitor goods and traffic, and is expected to play a role in enabling the large data transfers CAVs require.[130] Urban centres generally have better data-sharing infrastructure than rural communities (CBP-7069).[166] This limits technology use in rural areas and can make it challenging to locate some drop-off adresses.[167] The

Government has committed to improving broadband infrastructure in the UK (CBP-9156). The Shared Rural Network Programme aims to invest £1 billion in expanding 4G coverage from 91% to 95% by 2025.[168] The Government is supporting several freight-specific projects with the 5G Testbed and Trials Programme,[169,170] including investment in the Port of Felixstowe (£1.6 million) and Bristol Port (£2.5 million), supporting automation and goods tracking.[171]

Process standardisation and data sharing

The timely sharing of good-quality datasets underpins many of the technologies being explored for use in freight.[172,173] A challenge for emerging technology is a lack of standards for how data is collected and formatted.[174] This creates inconsistencies between different data sources and makes sharing difficult.[174] Standards for established freight technologies support port security,[175] the exchange of trade data,[176] bar code formatting[177] and outline requirements for logistics software to encourage data interchangeability.[178,179] Industry-led attempts exist to standardise collection processes for emerging technologies.[180] For example, in 2022 the Future International Trade Alliance formed aiming to standardise trade digitalisation for container shipping[181,182] and made progress towards a universal format for digital BoLs (Box 2).[183]

A 2022 report commissioned by DfT identified barriers to data sharing within the freight sector.[172] This found companies may be unable to dedicate resources towards the tools, staff and infrastructure required to collect data.[174,184] Companies may also be reluctant to share data perceived as commercially sensitive, or hesitant to collect information that may breach data sharing laws.[172,174] The NIC recommended that the Government develop a standard for freight data collection to support local authorities.[39] In response, the Government agreed better freight data is important and committed to work with industry to pilot methods to improve the exchange of data.[3,185]

Cybersecurity

Increasingly, reliance on digital tools in freight raises concerns that cyber-attacks could halt operations, enable fraudulent collection of goods, or impact the safety of CAVs.[186–189] In 2017, freight companies TNT and Møller-Maersk were affected by the NotPetya cyber-attack on businesses operating in Ukraine (PN 684).[190] This shut down computer systems of both companies, costing them each around $300 million in revenue.[191,192] Furthermore, experts have raised concerns that IoT devices provide a larger number of 'routes' to attack a network, and have a higher vulnerability to malware (PN 593).[193–195]

Employment and skills

According to DP World London Gateway, digital technology will lead to a skill-set shift, creating jobs in control, planning and engineering.[100] Responses from industry to a Call for Ideas by DfT's Transport Employment and Skills Taskforce[196] highlighted a need for advanced digital and IT skills in the sector, particularly in cybersecurity, data analytics, programming and software engineering.[133] Training programmes to develop skills in logistics include apprenticeships, undergraduate degrees and masters programmes.[197–200] Furthermore, online courses allow for flexible learning to help up-skill the existing workforce.[201] The Government has invested £345,000 in the industry-led Generation Logistics campaign. This aims to future-proof the industry[202] through using networking events, career development resources, and promoting job opportunities.[203,204]

Attitudes towards emerging technology

Some workers and members of the public have concerns about digital technologies in freight.[205] Examples include:

- **Reduced job security and satisfaction**. In a 2022 survey of warehouse workers, 40% of respondents expressed negative sentiments about automation and its potential to cause redundancy.[206,207] Also, in EU platooning trials, HGV drivers reported that platooning feels "unpleasant".[72,208,209]
- **Breaches of privacy.** Data collection systems can cause drivers anxiety about privacy, with research showing that 65% expressed concerns "data collected by in-vehicle technology will get into the wrong hands".[210] Stakeholders have also noted that the presence and noise of delivery drones over private property could be intrusive.[93,211,212]
- **Safety concerns.** In a 2021 survey of the public by DfT, CAV safety was a primary concern[213] The Government has stated CAVs should be safer than the average human driver and is currently consulting to develop safety requirements.[214] Another concern is the use of car satnav systems in HGVs, which resulted in collisions with bridges in Leicestershire and Swindon.[215,216] Councils are calling on the Government to require HGV drivers use specialist satnavs that avoid narrow roads and low bridges.[217]

Economic challenges

The freight industry is highly competitive,[18] and analysis of the top 100 UK road haulers and 3PLs found return on sales only averaged 2.3% in 2019.[218] The industry is also fragmented, with most companies being smaller operators.[72] This can limit investment in new technology, due to small budgets and concerns about stranded assets or first-mover disadvantages.[3] CAVs also have high implementation costs,[67] and trials must demonstrate substantial benefits to warrant industry adoption. For example, a 0.5% decrease in fuel consumption from a 2022 UK platooning trial was considered insufficient.[73,74,219]

Legislation and regulation

Legislative frameworks are being developed for some emerging technologies. The legal recognition of digital documents depends on the passing of the Electronic Trade Documents Bill (Box 2), which could provide a framework for 'digital ownership' of other assets.[220] Regulation is also required to guide the introduction of delivery CAVs. Key developments here include:

- **CAVs on public roads.** The Government plans to have a framework in place for the public introduction of self-driving vehicles by 2025.[71,221,222] The 2018 Automated and Electric Vehicles Act has already established how automated driving will be treated for insurance purposes (CBP 8118).[223]
- **Drones in shared airspace.** Most delivery drones must fly beyond the line of sight of an operator and in controlled airspace,[224] requiring Civil Aviation Authority (CAA) permission.[225] In 2020 the CAA initiated a test project, providing segregated airspace for safety testing.[226] AGS Airports is leading a trial that will inform regulation on drone use in shared airspace. This will run until 2024, using drones to deliver medical supplies in Scotland.[227,228]

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References

1. Department for Transport (2021). Domestic freight transport, by mode: 1953 to 2021 (TSGB0401).
2. Logistics UK (2022). The Logistics Report Summary 2022.
3. Department for Transport (2022). *Future of Freight: a long-term plan*.
4. Harris, I. *et al.* (2015). ICT in multimodal transport and technological trends: Unleashing potential for the future. *International Journal of Production Economics*, Vol 159, 88–103.
5. Wang, Y. (2019). *Understanding the impact of emerging technologies on the freight sector*. Government Office for Science.
6. Theis, T. N. *et al.* (2017). The End of Moore's Law: A New Beginning for Information Technology. *Computing in Science & Engineering*, Vol 19, 41–50.
7. McCarthy, P. (2017). Infographic: The Growth of Computer Processing Power. *RECOIL OFFGRID*.
8. Khatib, E. J. *et al.* (2021). Optimization of 5G Networks for Smart Logistics. *Energies*, Vol 14, 1758. Multidisciplinary Digital Publishing Institute.
9. Barbee, J. *et al.* (2021). Optimizing warehouse automation for retailers. McKinsey & Company.
10. UK5G (2022). 5G in Action: Intelligent Transport Systems Freight.
11. Lu, W. *et al.* (2014). The Role of Distributed Intelligence in Warehouse Management Systems. in *Service Orientation in Holonic and Multi-Agent Manufacturing and Robotics*. (eds. Borangiu, T. et al.) 63–77. Springer International Publishing.
12. van der Muelen, R. *et al.* (2014). Gartner Says Supply Chain Management Software Revenue Is on Course to Reach $10 Billion in 2014.
13. Maciuk, K. (2018). The applications of GNSS systems in logistics. *Budownictwo i Architektura*, Vol 17,
14. Wang, Y. *et al.* (2011). A case study exploring drivers and implications of collaborative electronic logistics marketplaces. *Industrial Marketing Management*, Vol 40, 612–623.
15. Fetch robotics (2021). AMR-only optimization versus AMRs as part of entire warehouse optimization. Interact Analysis.
16. Christiansen, B. (2022). Warehouse Robots: Friends Or Foes For Warehouse Employees. Warehouse & Logistics News.
17. Fetch robotics (2021). AMR Solution Guide. ZEBRA technologies.
18. MDS Transmodal (2019). Understanding the UK freight transport system. Government Office for Science.
19. Department for Transport (2023). £7 million tech fund to decarbonise freight and boost innovation.
20. Innovate UK (2022). Zero emission road freight demonstrations 2022.
21. Department for Transport (2022). £200 million boost to rollout of hundreds more zero-emission HGVs. GOV.UK.
22. Department for Transport (2022). DfT launches UK SHORE to take maritime 'back to the future' with green investment. GOV.UK.
23. The Royal Society (2020). Digital technology and the planet: harnessing computing to achieve net zero.
24. Department for Digital, Culture, Media & Sport (2021). Our Ten Tech Priorities.
25. Department for Transport (2021). Decarbonising Transport – A Better, Greener Britain.
26. Office for Artificial Intelligence (2021). National AI Strategy. GOV.UK.
27. Centre for Connected and Autonomous Vehicles (2022). Connected and automated vehicles: process for assuring safety and security (CAVPASS).
28. Department for Business (2022). Self-driving buses, shuttles and delivery vans could soon hit UK roads thanks to £40 million government-funded competition.
29. Innovate UK (2022). Commercialising connected and automated mobility: deployments.
30. Vega, A. (2021). Logistics operators: an overview.
31. Rodrigue, J. *et al.* (2020). Road Transportation. The Geography of Transport Systems.
32. Department for Transport (2003). A simplified guide to lorry types and weights.
33. Paddeu, D. (2017). The Bristol-Bath Urban freight Consolidation Centre from the perspective of its users. *Case Studies on Transport Policy*, Vol 5, 483–491.
34. Department for Transport (2021). Transport Statistics Great Britain: 2021. *GOV.UK*.
35. Department for Transport (2016). Rail Freight Strategy. 57.
36. Rail Delivery Group (2021). Assesing the Value of Rail Freight. Deloitte.
37. Akarca, O. (2019). The Most-Common Cargo Vessel Types. *More Than Shipping*.
38. Rodrigue, J.-P. *et al.* (2020). Maritime Transportation. The Geography of Transport Systems.
39. National Infrastructure Commission (2019). Better Delivery: The Challenge For Freight - Freight Study final report.
40. Bowen, J. *et al.* (2020). Air Transport. The Geography of Transport Systems.
41. Paddeu, D. (2022). The future of last-mile deliveries: Understanding the local perspective. Local Government Association.
42. Office for National Statistics (2022). Internet sales as a percentage of total retail sales (ratio) (%).
43. Ofcom (2022). Online Nation 2022 Report.
44. Hannon, E. *et al.* (2020). Rethinking last-mile logistics, post-COVID-19: Facing the 'next normal'. Automotive World.
45. Department for Transport (2021). *Final Van Statistics 2019-20*.
46. 123Intermet (2021). New report reveals major growth and seismic changes in UK warehousing sector. *UKWA*.
47. Office for National Statistics (2022). The rise of the UK warehouse and the "golden logistics triangle".
48. Knight Frank (2021). Ecommerce growth driving record warehouse development in 2021 - Knight Frank.
49. Grondys, K. *et al.* (2014). IMPORTANCE OF LOGISTICS OPERATORS IN INTERNATIONAL MARKET. *Advanced Logistic Systems - Theory and Practice*, Vol 8, 41–46.
50. Hawkins, A. (2021). 3PLs vs 4PLs vs 5PLs: What's the Difference? extensiv.
51. Hanus, P. (2013). THE BUSINESS PROFILE SHAPING AND THE LOGISTICS INFORMATION SYSTEMS OF 2PL, 3PL, 4PL OPERATORS. *Journal of Economics & Management*, 18.
52. Xiu, X. (2010). Study of Collaborative Information Systems of 4PL Based on Internet. in *2010 Second International Conference on Modeling, Simulation and Visualization Methods*. 206–209.
53. Gruchmann, T. *et al.* (2020). 4PL Digital Business Models in Sea Freight Logistics: The Case of FreightHub. *Logistics*, Vol 4, 10. Multidisciplinary Digital Publishing Institute.
54. Rodrigue, J.-P. *et al.* (2020). Intermodal Transportation and Containerization. The Geography of Transport Systems.
55. Rodrigue, J. *et al.* (2020). The Function of Transport Terminals. The Geography of Transport Systems.
56. Department for Transport (2020). Position statement on last mile logistics. GOV.UK.
57. Keshavdas, M. (2022). What Are The Challenges Of A Last Mile Delivery System? Fleetroot.
58. sustrans (2020). Reinventing transport: planning for e-cargo bikes.
59. Blazejewski, L. *et al.* (2020). Delivering the last mile: scoping the potential for E-cargo bikes.
60. Department for Transport (2021). *Domestic Road Freight Statistics, United Kingdom 2020*.

61. Department for Transport (2015). Road Investment Strategy: for the 2015/16 – 2019/20 Road Period. 160.
62. Office of Rail and Road (2022). Table 1333 - Freight train kilometers by operator.
63. SAE international (2021). J3016_202104: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.
64. Hopkins, D. *et al.* (2021). Talking about automated vehicles: What do levels of automation do? *Technology in Society*, Vol 64, 101488.
65. CloudFactory (2021). Breaking Down The Levels of Drone Autonomy.
66. (2022). Automatic train operation. *Wikipedia*.
67. Paddeu, D. *et al.* (2019). New Technology and Automation in Freight Transport and Handling Systems. *Government Office for Science*,
68. Shaout, A. *et al.* (2011). Advanced Driver Assistance Systems - Past, present and future. in *2011 Seventh International Computer Engineering Conference (ICENCO'2011)*. 72–82.
69. Nast, C. (2017). Your Pilot Isn't Actually Flying Your Plane. *Condé Nast Traveler*.
70. SeaNews (2018). Understanding the Autopilot System on Ships.
71. Department for Business, Energy & Industrial Strategy *et al.* (2022). Connected & Automated Mobility 2025: Realising the benefits of self-driving vehicles in the UK. HM Government.
72. Paddeu, D. *et al.* (2022). Decarbonising road freight: Is truck automation and platooning an opportunity? *Clean Techn Environ Policy*, Vol 24, 1021–1035.
73. Department for Transport (2014). Truck platooning: UK road trial feasibility study.
74. HelmUK (2022). HelmUK Final Report.
75. Alstom (2022). Alstom takes another step towards Autonomous Train Operation in the Netherlands.
76. Harriss, L. (2022). Moving Block Signalling.
77. Hitachi Ltd (2020). Robot Trains: How Hitachi Rail Tech Enabled Global First in Heavy Freight Rail Automation.
78. CB Insights Research (2018). Autonomous Shipping And What It Means For Global Trade. *CB Insights Research*.
79. Maritime & Coastguard Agency (2020). Maritime Autonomy Regulation Lab (MARLab) Report. GOV.UK.
80. AAWA (2016). Remote and Autonomous Ships: The next steps. Rolls-Roycs plc.
81. Kongsberg (2021). Autonomous ship project, key facts about YARA Birkeland.
82. Writer, C. S. (2019). Amazon's New Delivery Drone: Five Key Things We Know So Far. *Tech Monitor*.
83. Federal Aviation Administration (2022). Airworthiness Criteria: Special Class Airworthiness Criteria for the Amazon Logistics, Inc. MK27-2 Unmanned Aircraft. *Federal Register*.
84. nesta (2018). Medical delivery in London. Industrial Strategy Council.
85. Engelking, C. (2015). Drone Delivery Services Are Booming In China. *Discover Magazine*.
86. Vallance, C. (2022). Royal Mail wants fleet of 500 drones to carry mail to remote UK communities. *BBC News*.
87. Royal Mail Group Ltd (2021). Drones: connecting remote communities across the UK. *Royal Mail*.
88. Warrington, J. (2022). Royal Mail shelves plans to deliver via drones as strikes cripple business. *The Telegraph*.
89. Boxall, A. (2017). How the Ocado CargoPod Autonomous Delivery Vehicle Works. *Digital Trends*.
90. Molfino, R. *et al.* (2015). An electro-mobility system for freight service in urban areas. *IJEHV*, Vol 7, 1.
91. Vincent, J. (2020). This walking package-delivery robot is now for sale. *The Verge*.
92. Kim, J. *et al.* (2022). Robot Routing Problem of Last-Mile Delivery in Indoor Environments. *Applied Sciences*, Vol 12, 9111. Multidisciplinary Digital Publishing Institute.
93. Paddeu, D. *et al.* (2020). The potential for automation to transform urban deliveries: Drivers, barriers and policy priorities. in *Advances in Transport Policy and Planning*. (eds. Milakis, D. et al.) Vol 5, 291–314. Academic Press.
94. Lääne, J. (2021). How Starship Delivery Robots know where they are going. *Starship Technologies*.
95. Generation Logistics (2022). DPD UK To Start Using Autonomous Delivery Robots. *Generation Logistics*.
96. Cambridgeshire County Council (2022). Delivery robots now available to Cambridge residents under new pilot scheme.
97. Gardner, N. (2020). A brief guide to container terminal automation. *Thetius*.
98. Chu, F. *et al.* (2018). The future of port automation. McKinsey & Company.
99. Široký, J. (2011). Automatic Transhipment Systems for Container Transport in Terminals. *Perner's Contacts*, Vol 6, 145–154.
100. DP World London Gateway (2018). DP World London Gateway: The definitive guide.
101. Ackerman, E. (2021). A Robot for the Worst Job in the Warehouse. IEEE Spectrum.
102. Jackson, T. (2017). The flying drones that can scan packages night and day. *BBC News*.
103. Shama, A. (2022). UK Set To Become Europe's Largest Warehouse Automation Opportunity. Interact Analysis.
104. Scriven, R. (2019). UK Warehouse Automation Market: Boom or Bust? Interact Analysis.
105. McKinsey Global Institute (2015). The Internet of Things: Mapping the value beyond the hype.
106. Sarac, A. *et al.* (2010). A literature review on the impact of RFID technologies on supply chain management. *International Journal of Production Economics*, Vol 128, 77–95.
107. Komoni, K. (2020). How to Track Shipments with Disposable GPS Trackers. *Tive*.
108. Faugère, L. *et al.* (2020). Smart locker bank design optimization for urban omnichannel logistics: Assessing monolithic vs. modular configurations. *Computers & Industrial Engineering*, Vol 139, 105544.
109. Yamsaengsung, S. *et al.* (2018). Towards Improving User Interaction with Navigation Apps: an Information Quality Perspective. *KnE Social Sciences*, 119–131.
110. Armbrust, M. *et al.* (2010). A view of cloud computing. *Commun. ACM*, Vol 53, 50–58.
111. Trade Facilitation Implementation Guide (2012). Port community systems. United Nations.
112. CSS-UK (2023). The CSS-UK Cargo Community User Group Ltd.
113. PortXchange (2022). Digital collaboration Platform | Maritime logistics. *PortXchange*.
114. Government Office for Science (2016). *Distributed Ledger Technology: beyond block chain*. 88.
115. Soni, A. (2020). IoT and blockchain: Technologies for universal cargo monitoring IBM Supply Chain and Blockchain Blog. *IBM Supply Chain and Blockchain Blog*.
116. Observatory of Public Sector Innovation (2020). Reducing Friction in Trade (RFIT).
117. Law Commission (2022). Electronic trade documents | Law Commission.
118. DCSA (2022). Streamlining international trade by digitalising end-to-end documentation. *DCSA*.
119. Dearnaley, E. (2021). Smarter Contracts.
120. Austin, N. (2020). 5 ways weather impacts freight shipments. *FreightWaves*.
121. Walker, J. (2019). AI for Weather Forecasting - In Retail, Agriculture, Disaster Prediction. *Emerj Artificial Intelligence Research*.

122. McKevitt, J. (2017). IBM subsidiary Weather Co. brings real-time weather data for drivers, dispatchers. *Supply Chain Dive*.
123. Tao, F. *et al.* (2019). Digital Twin in Industry: State-of-the-Art. *IEEE Transactions on Industrial Informatics*, Vol 15, 2405–2415.
124. Jenkins, A. (2020). Warehouse Automation: The How, When & Why. *Oracle NetSuite*.
125. Fedotov, A. A. *et al.* (2020). The digital twin of a warehouse robot for Industry 4.0. *IOP Conf. Ser.: Mater. Sci. Eng.*, Vol 862, 032061. IOP Publishing.
126. Shakya, S. *et al.* (2022). Leveraging AI for Asset and Inventory Optimisation. *Cardiff University Press*, Cardiff University Press.
127. Engineering & Physical Science Research Council (2022). Leader for research in digital twinning for decarbonising transport. UKRI.
128. Zaccaria, V. *et al.* (2018). Fleet Monitoring and Diagnostics Framework Based on Digital Twin of Aero-Engines. in American Society of Mechanical Engineers Digital Collection.
129. Lyness, M. (2020). IoT-enabled predictive maintenance in rail. *Capita*.
130. national highways (2021). Digital Roads. National Highways.
131. Office for National Statistics (2021). UK business; activity, size and location.
132. UK Government (2021). UK government action to reduce the HGV driver shortage. *GOV.UK*.
133. Department for Transport (2022). Transport Labour Market and Skills Call for Views and Ideas. 20.
134. Daily, I. B. (2022). Too Few Workers Means More Robots In Warehouses. *Investor's Business Daily*.
135. Lawence, M. *et al.* (2017). Managing Automation: Employment, inequality and ethics in the digital age.
136. Frey, C. B. *et al.* (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change*, Vol 114, 254–280.
137. vivideconomics (2019). The value of freight. National Infrastructure Commission.
138. Camhi, J. *et al.* (2017). Amazon looks to further logistics automation. *Business Insider*.
139. Bhattacharya, A. (2016). Amazon is just beginning to use robots in its warehouses and they're already making a huge difference. *Quartz*.
140. Zarif, R. *et al.* (2021). Autonomous trucks lead the way. *Deloitte Insights*.
141. Keeney, T. (2017). Autonomous Trucks Could Disrupt Rail and Transform Logistics. *ARK Invest*.
142. Paddeu, D. *et al.* (2018). Multi-stakeholder collaboration in urban freight consolidation schemes: drivers and barriers to implementation. *Transport*, Vol 33, 913–929.
143. Roberts, D. (2013). Big Data in Logistics - A DHL perspective on how to move beyond the hype.
144. Vargas, A. *et al.* (2018). Towards a Business Model Framework to Increase Collaboration in the Freight Industry. *Logistics*, Vol 2, 22. Multidisciplinary Digital Publishing Institute.
145. returnloads.net (2022). Haulage exchange and back loads.
146. Department for Transport (2017). Freight Carbon Review 2017.
147. returnloads.net (2022). Sustainable Transport & Green Haulage. *returnloads.net*.
148. Department for Transport (2022). Provision of Kerbside Management Discovery. *GOV.UK - Digital Marketplace*.
149. Vianova (2022). Mobility Data Platform for Cities & Transport Providers. *Vianova*.
150. AppyWay (2022). Kerbside Management, Mobility & Parking Solutions. *AppyWay*.
151. Herron, N. (2021). Dynamic kerb management will deliver the goods. *Parking Review*.
152. (2022). Kale Collective.
153. InPost (2021). InPost partners with Salford City Council to install new parcel lockers across the borough. *InPost*.
154. Department for Transport (2022). Decarbonising road freight, servicing and deliveries: local authority toolkit. *GOV.UK*.
155. Quarshie, N. *et al.* (2021). Worth the Weight: Making London's deliveries greener and smarter. 59.
156. Ambler, P. (2017). Diamonds Are The Latest Industry To Benefit From Blockchain Technology. *Forbes*.
157. Coronado Mondragon, A. E. *et al.* (2021). Managing the food supply chain in the age of digitalisation: a conceptual approach in the fisheries sector. *Production Planning & Control*, Vol 32, 242–255.
158. Contained Technologies UK Ltd (2022). Fresh Food Logistics.
159. Department for Transport (2022). Tachographs: rules for drivers and operators. *GOV.UK*.
160. Stoneridge (2016). Smart Tachograph 2019. *Stoneridge*.
161. Cabinet Office (2022). UK Single Trade Window - Policy discussion paper. *GOV.UK*.
162. Cabinet Office (2020). 2025 UK Border Strategy. *GOV.UK*.
163. ICC UK (2021). United Kingdom - Creating Modern Digital Trade Ecosystem.
164. ICC UK (2021). Creating a Modern Digital Trade Ecosystem.
165. DCMS (2018). Future Telecoms Infrastructure Review.
166. 5G.co.uk (2022). 5G Coverage Checker – Compare coverage on all UK networks. *5G.co.uk*.
167. Building Digital UK (2022). Benefits of Rural Mobile Coverage. *Network (SRN) consultation docume*.
168. Building Digital UK (2022). Shared Rural Network (SRN) consultation document. *GOV.UK*.
169. Millbrook (2022). UK's 5G Test Bed for Connected and Autonomous Vehicles. *UTAC*.
170. Department for Digital, Culture, Media & Sport (2021). 5G Testbeds and Trials Programme: complete list of 5G projects. *GOV.UK*.
171. West England Combined Authority (2021). 5G Logistics. *West England Combined Authority*.
172. Connected Places Catapult (2022). Transforming the use of freight and logistics data to inform investment and policy decisions. *Connected Places Catapult*.
173. Manson, R. *et al.* Future of mobility: freight and the sharing economy. Government Office for Science.
174. Moschovou, T. *et al.* (2019). Challenges for data sharing in freight transport. *Working Paper Series*,
175. Gould, R. (2020). Shaping shipping. ISO.
176. UNECE (2022). Streamlined presentation of UN/CEFACT standards. United Nations.
177. BSI (2015). BS EN 1573:2015 | Bar code. Multi industry transport label.
178. BSI (2021). BS ISO 37180:2021 | Smart community infrastructures. Guidance on smart transportation with QR code identification and authentification in transportation and its related or additional services.
179. BSI (2020). BS ISO 23354:2020 | Business requirements for end-to-end visibility of logistics flow.
180. ODI (2020). The Value of Data Sharing in the Private Sector: Benchmarking and Insights. *HiLo Maritime risk management*.
181. ICC (2022). Future International Trade Alliance launched. *International Chamber of Commerce*.
182. Bagge, T. (2022). The Future International Trade Alliance explained. *DCSA*.
183. Wragg, E. (2022). Shipping industry bodies link up with ICC and Swift to form digitalisation alliance. *Global Trade Review*.
184. Busby, A. *et al.* (2020). Motivations for and barriers to data sharing. Department for Digital, Culture, Media & Sport.

185. Department for Transport (2021). Government Response to Better Delivery: A Challenge for Freight. 23.
186. (2020). Top 5 Threat Vectors in Connected Cars and How to Combat Them. *Security Intelligence*.
187. Parkinson, S. *et al.* (2017). Cyber Threats Facing Autonomous and Connected Vehicles: Future Challenges. *IEEE Transactions on Intelligent Transportation Systems*, Vol 18, 2898–2915.
188. Chown, P. (2023). 10 Steps to Prevent Logistics Cyber Attacks and Protect Your Operations. *track-pod.com*.
189. Kron technologies (2022). Cybersecurity in the Logistics Industry. *krontech.com*.
190. Baraniuk, C. (2017). Customers 'furious' with TNT after cyber-attack meltdown. *BBC News*.
191. Milne, R. (2017). Moller-Maersk puts cost of cyber attack at up to $300m. *Financial Times*.
192. BBC News (2017). NotPetya cyber-attack cost TNT at least $300m. *BBC News*.
193. The IEEE Standards Association (2022). Why Cybersecurity Is Key to IoT Sensors. *ieeespectrum*.
194. Wang, Y. *et al.* (2022). A primer on digital supply chain transformation. in (eds. Wang, Y. et al.) Cardiff University Press.
195. Lee, I. (2020). Internet of Things (IoT) Cybersecurity: Literature Review and IoT Cyber Risk Management. *Future Internet*, Vol 12, 157. Multidisciplinary Digital Publishing Institute.
196. UK Government (2022). Transport employment and skills taskforce. *GOV.UK*.
197. GOV.UK (2023). Training providers for Supply chain leadership professional (integrated degree) (level 6).
198. Northumbria University (2023). MSc Global Logistics Operations and Supply Chain Management (with Advanced Practice).
199. The Chartered Institution of Logistics and Transport (2023). Your Professional Development Pathway.
200. The complete university guide (2023). Undergraduate Logistics Courses.
201. The Institute of Supply Chain Management (2023). Supply Chain Training Courses. *Institute of Supply Chain Management*.
202. Logistics Magazine (2022). Generation Logistics – attracting future talent into the industry. *Logistics UK*.
203. (2022). Generation Logistics.
204. Department for Transport (2022). Boost for freight as government unveils major new plan to bolster supply chain. *GOV.UK*.
205. Guerra, E. (2016). Planning for Cars That Drive Themselves: Metropolitan Planning Organizations, Regional Transportation Plans, and Autonomous Vehicles. *Journal of Planning Education and Research*, Vol 36, 210–224. SAGE Publications Inc.
206. Lui, J. *et al.* (2022). Research: How Do Warehouse Workers Feel About Automation? *Harvard Business Review*.
207. Wagner, N. *et al.* (2021). Attitude of employees towards emerging technologies used in intralogistics. *Procedia Computer Science*, Vol 192, 3184–3193.
208. Eilers, S. *et al.* (2015). COMPANION – Towards Co-operative Platoon Management of Heavy-Duty Vehicles. in *2015 IEEE 18th International Conference on Intelligent Transportation Systems*. 1267–1273.
209. COMPANION (2016). D2.7—documentation of the exploitation of the results. European Commission, 27 September. European Commission, 27 September.
210. Huang, Y.-H. *et al.* (2005). Feedback by technology: Attitudes and opinions of truck drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol 8, 277–297.
211. Kunze, O. (2016). Replicators, Ground Drones and Crowd Logistics A Vision of Urban Logistics in the Year 2030. *Transportation Research Procedia*, Vol 19, 286–299.
212. The Week (2021). How close is the UK to using delivery drones? *The Week UK*.
213. The Department for Transport (2021). Future of transport: deliberative research. *GOV.UK*.
214. Centre for Connected and Autonomous Vehicles (2022). Self-driving vehicles: new safety ambition. *GOV.UK*.
215. Angelini, D. (2021). Wootton Bassett Road reopened after lorry hits bridge. *Swindon Advertiser*.
216. BBC East Midlands (2022). Lorry strikes railway bridge and sheds paint over road. *BBC News*.
217. Stop bridge chaos by banning faulty satnavs, say councils | Local Government Association.
218. Motor Transport (2020). Motor Transport Top 100 2020. *Motor Transport Top 100*.
219. Department for Transport (2018). Technology and RIS2.
220. Law Commission (2022). Digital assets.
221. Catapult Connected Places (2019). *Connected Places Catapult | market forecast for connected and autonomous vehicles*.
222. Department for Transport (2022). Automated Vehicles: the Highway Code update. 10.
223. (2018). Automated and Electric Vehicles Act 2018. *Legislation.gov.uk*. Queen's Printer of Acts of Parliament.
224. Green, H. (2018). Drone Guide to Understanding Airspace. *Drone Safe Register News and Blog*.
225. Kim, T. (2020). *Non-Segregated BVLOS*. UK Civil Aviation Authority.
226. Civil Aviation Authority (2021). Drone trial of routine BVLOS operations concept authorised.
227. AGS Airports (2022). We Are Project CAELUS.
228. Dronamics (2022). Dronamics joins UK's first medical drone distribution network.