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The Big UK Data Centre Equipment Opportunity

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Contents

1 Executive summary

Data is at the core of the modern economy. Manufactured goods accumulate data throughout the supply chain, money is stored and exchanged electronically, performance and services are digitally monitored. Data uniquely unites the service and manufacturing sectors — essential to one and all.

The growth of the digital economy depends 100% on accessing, processing and storing data. This generates a £40bn market in the UK for data centres (DCs) and the networking, storage, processing cooling and power equipment they contain. These facilities are also major electricity users, consuming the output of approximately one and a half nuclear power stations.

With huge demands for growth, the DC market is simultaneously maturing and fragmenting. As different segments from online entertainment to security simultaneously reach critical mass, the demands they place on DC equipment are diverging as it becomes increasingly hard for one product to meet all performance and cost requirements. For many consumer markets, e.g. online shopping, the DC is a back office cost — critical but unseen, where costs need to be minimised through scale and performance optimisation. Mega DCs have applications in extremely competitive global markets, hungry for next-generation technologies. Open to rapidly adopting innovation, these present opportunities for UK companies and technologies prepared to overcome the barriers of scale, although few of these mega DCs will be located in the UK.

However, mega DCs are <50% of the global market and much less in the UK. Instead, the UK is home to facilities hosting customers who care much more about the physical location of their data. This can be because of legal, security or societal restrictions but the biggest opportunity is in DCs associated with financial trading. To the City of London, data location impacts the speed of trading and thus the value of >£5 trillion financial securities exchanged per year. Providing DC technologies optimised for high speed trading, where the time to exchange and process data (latency) is equally important as the data capacity, is essential to keeping London competitive and keeping the UK a major international financial centre. The past decade has seen a move from the physical trading floor to the anonymous DC, populated with generic imported equipment; the next decade will see these systems optimised for the unique requirements of a DC. This presents a major opportunity for the UK to supply latency and security-optimised hardware to the local financial services sector and other proximity-sensitive DC markets worldwide.

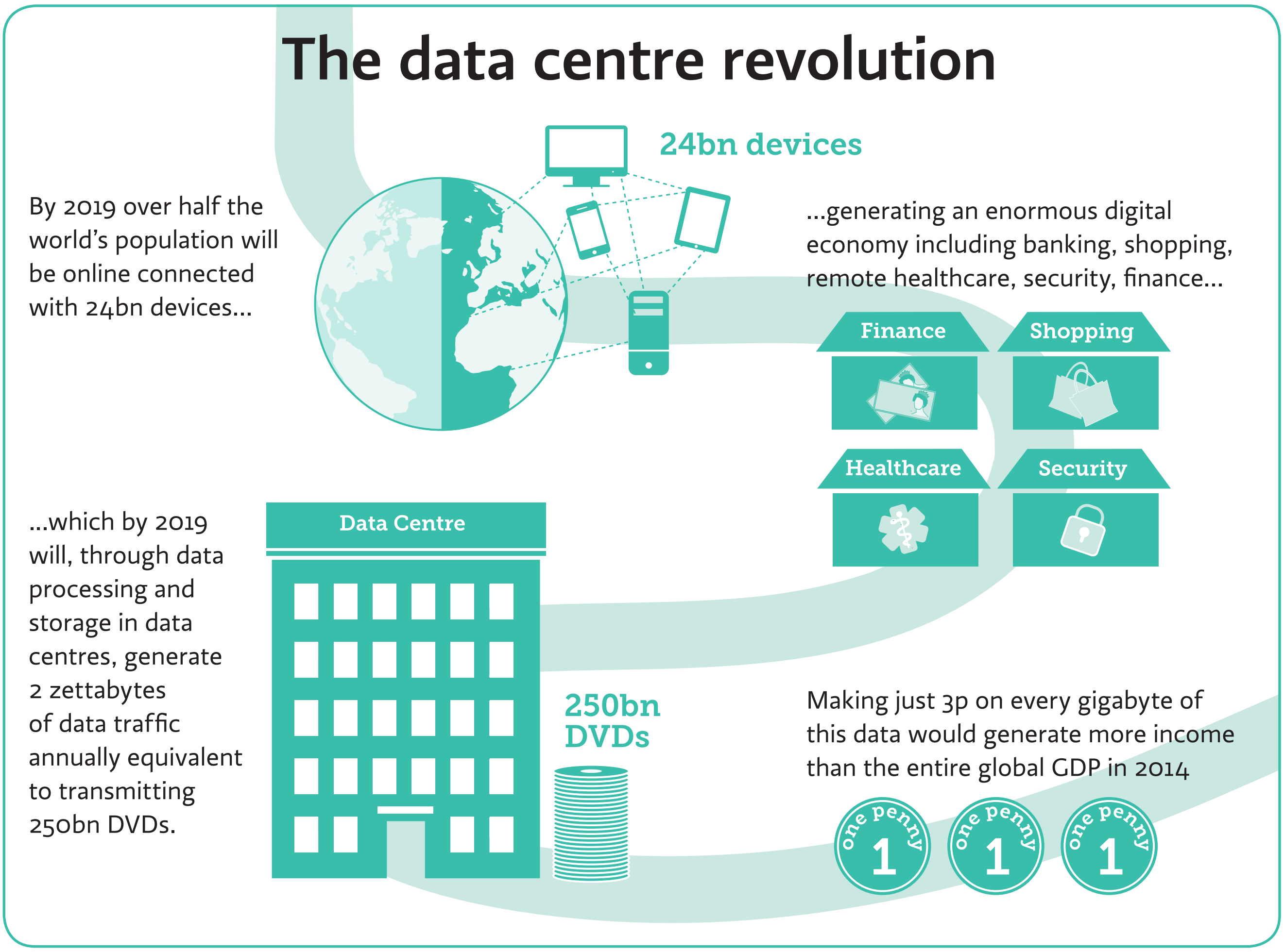
The UK has a globally leading data, optical communications and storage innovation base, is home to the world's leading financial trading houses and is the birthplace of energy-efficient computing. However, there is currently little overlap between these communities, meaning opportunities are being missed in providing next-generation solutions for financial services and other proximity-sensitive DCs. Developing solutions requires bringing these communities together to create a common understanding of the potential of UK technology, who is positioned to take that innovation to market, and how this can be translated into a competitive advantage and reduce risk.

2 Introduction

Data is the new lifeblood of industry and society. By 2019 over half the world's population will be online with 3.9bn internet users, connected with 24bn devices[1]. This connected world is generating an enormous digital economy covering everything from banking and shopping to remote healthcare, security and finance. An intimate part of this new economy is the remote storage[2] and processing of data[3] in data centres (DCs). By 2019 this will generate two zettabytes of data traffic annually, equivalent to transmitting 250bn DVDs. Making just three pence on every gigabyte of that data would generate more income than the entire global GDP in 2014.[4]

This provides a huge opportunity in services and in the hardware equipment on which that data is moved, stored and processed. This is not just a capacity, capability and security challenge — moving and processing data requires electricity. UK DCs use ~1.5 nuclear power stations' worth of electricity, enough to power ~3.8m UK homes or 14% of all UK households. For both environmental and cost reasons, reducing this energy consumption is essential.

This report is for those looking to understand how the UK can make the most of the DC revolution through the development, manufacture and deployment of next-generation hardware. This hardware is increasingly based on optical technology — an area in which the UK excels — and opportunities where UK's technology advantage can be applied to specific local market demands are clearly identified. The objective is to provide the key trends that frame the opportunity, what actions may accelerate UK technology and provide a direct link between the service sector economy (whose raw material is data) and UK hardware development and manufacture.



3 Market structure

The DC value chain has four key levels indicated in Figure 1.

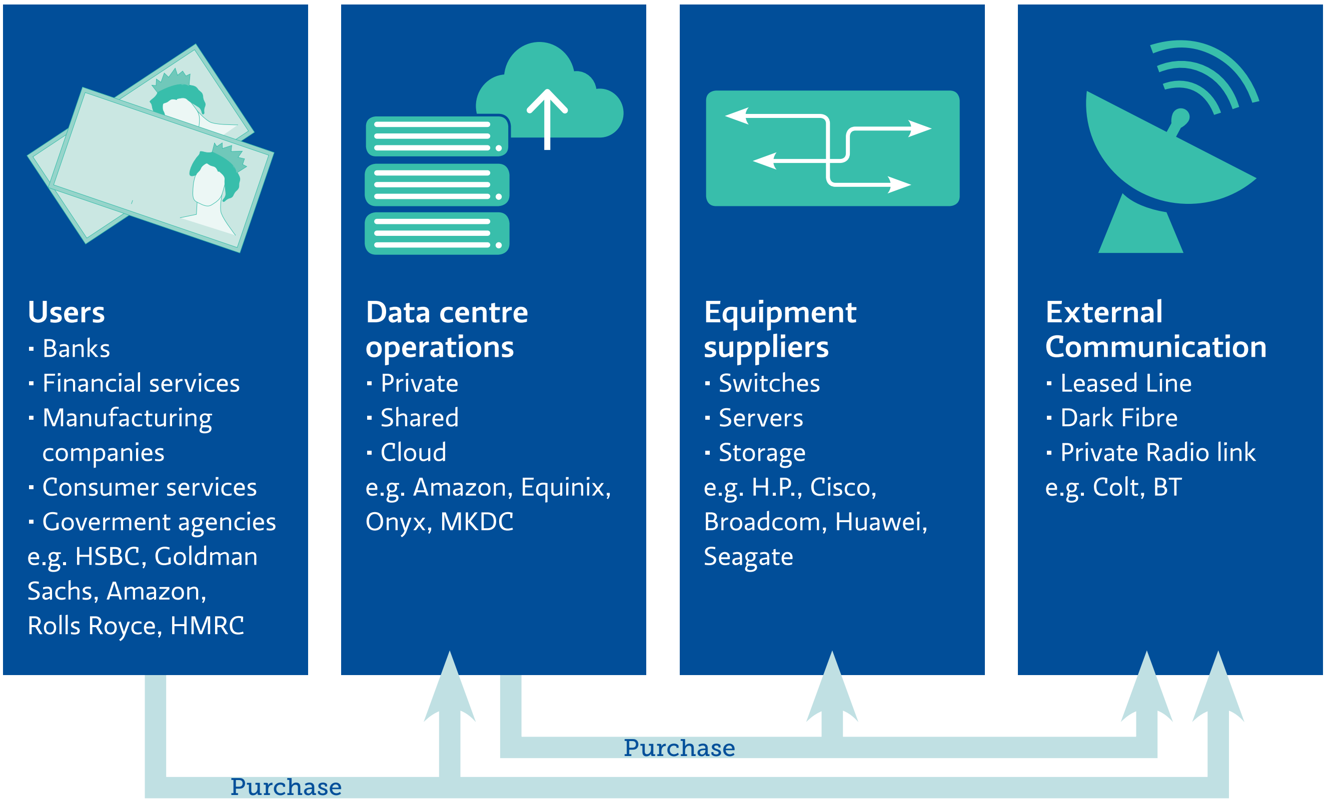


Figure 1: Top level data centre value chain. Non-exhaustive examples from the UK.

The connections within the value chain are, however, complex, with two distinct types of relationship between end users and DC operators:

- Hosting — where users pay to have their data stored or processed by the DC who operates, maintains and owns the capital equipment.
- Renting/remote hosting — where the client rents floor or rack space in the DC for their own equipment, with the DC providing central facilities, e.g. power and cooling. The external communications can also be provided by the DC, with all users inside the DC sharing that capacity, or the telecom providers may provide DC hosting as a service to its customers. Alternatively, a client may have a dedicated private link and have their own relationship with an external network provider with the DC promoting itself as independent of any individual telecommunications carrier.[5]

These variations create differences in where the responsibility resides for the provision, procurement, maintenance and allocation of hardware — either with the user or with the DC operator.

3.1 Global and UK market

The overall global DC market was worth ~$150bn in 2014,[6,7] growing at 9–10% per year. Already there is over 1.8bn square feet of DC space in 8.6m DCs worldwide,[8] 6% of which is in the UK,[9] where there are ~250 collocation DCs and 1000s more enterprise DCs within companies.

Data centre equipment $114bn			
Networking • Switches • Transceivers • Copper and fibre network cabling • Cable management	**Storage** • Disk drive raid arrays • Drive controllers • Archive storage • Solid state memory	**Computing** • Hardware • Blade servers • Rack servers • Software • Management software • Software defined network • Client software	**Plant** • Electrical • Rack power supplies • Back-up power supplies • Generators • Coolinh • Air conditioning • Water cooling • Racks

Figure 2 Breakout of key data centre components, with value of most relevant sectors.

The market for equipment in those centres was worth ~$114bn in 2014/15 and forecast to grow by at least 14% annually,[10] driven by the replacement of existing equipment and new DC built. The break down is shown in Figure 2.[11] All of these segments are growing by at least 10% annually, e.g. networking equipment is forecast to be worth $22bn by 2018,[12] up from ~$10bn in 2014;[13] cloud storage $65bn by 2020, up from $19bn in 2015;[14] and DC servers $44bn by 2019, up from $35bn in 2015.[15]

The UK is the leading market in Europe for DC equipment.[16] Over £20bn is spent on DC equipment each year in the UK, 24% of the EU total and growing at over 8% annually.[17]

3.2 Global trends

Time, speed, cost, capacity, security and energy to move and process data are all critical in the rapid evolution in DCs, illustrated in Figure 3, leading to a number of ongoing market trends.

3.2.1 Virtualisation

In a modern DC, computing tasks are no longer allocated to a dedicated server. Instead tasks are allocated to a number of virtual servers connected with a software-defined network.[18] If the load increases, more computing power and network bandwidth can be allocated with the required interconnectivity assigned on the fly. Hardware utilisation rates in such DCs can be much higher and enable systems to respond to peaks in demand — but this is not without cost.

Virtualisation has seen a rapid rise in so called East-West network traffic within DCs, i.e. data traffic that is purely internal to the DC as opposed to North-South traffic destined for locations outside the DC. For every byte of data that makes it to the outside world, 60 times more flows around inside the DC. This changes the type of network structure, speed and bandwidth required in the DC, driving rapid change in the DC networking equipment.[19] By 2019, DC IP traffic will reach 10.4 zettabytes per month or ~4 petabytes per second, growing at 25% every year.[3]

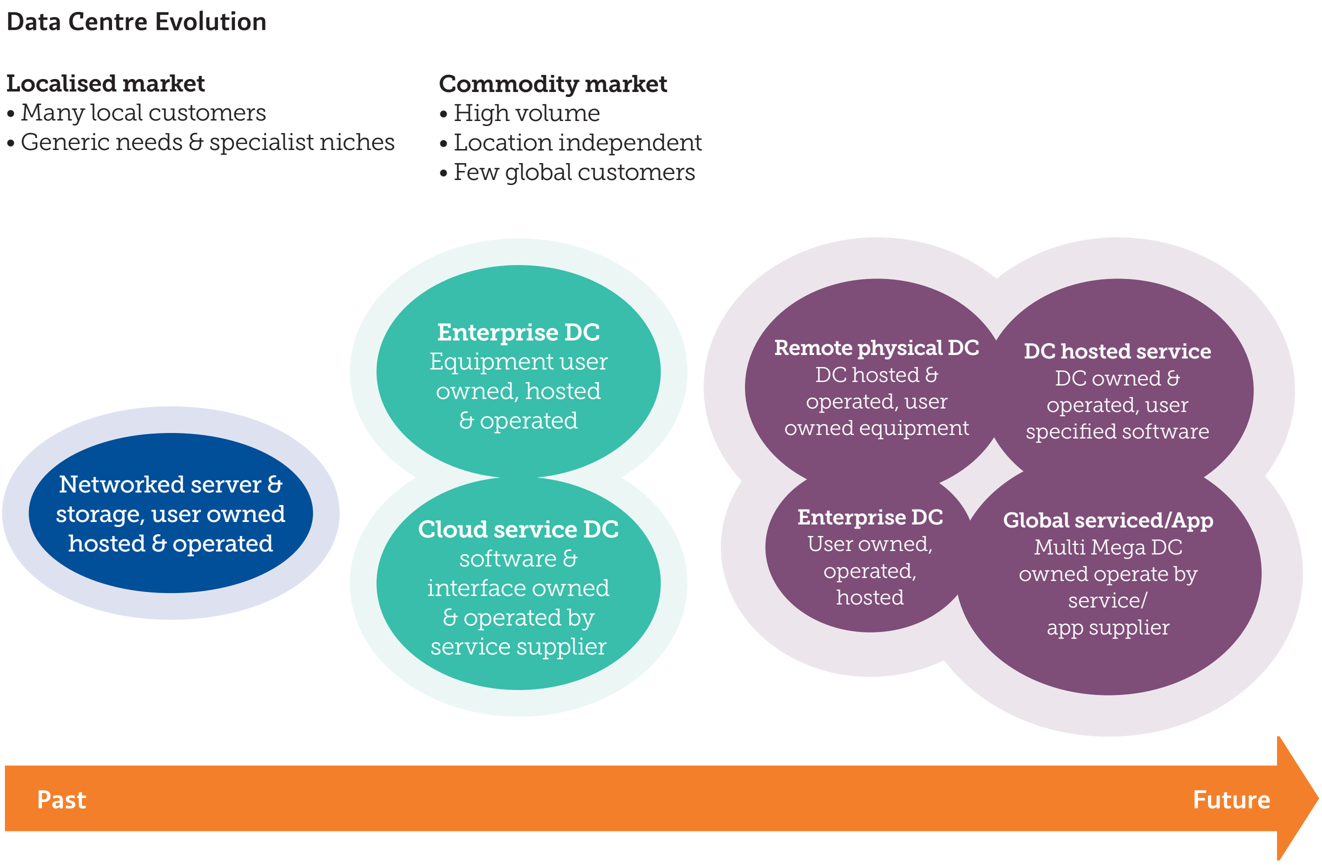


Figure 3 Growth and progressive segmentation of the data centre.

3.2.2 The rise of the mega data centre

The past decade has seen a huge increase in the use of cloud-based services, e.g. Dropbox, Netflix and global consumer platforms such as Facebook, Amazon and Google. This has driven a rapid growth in mega DCs, which are frequently owned and operated by these service providers, each containing thousands of computer servers, storage arrays and data switches. Google and Microsoft already have over 1m servers in their DCs.

By 2018 mega DCs will account for 45% of all new DC space (up from 20% in 2013), equivalent to an additional 30m square feet per year.[20] The rapid pace of technology development also means equipment-replacement cycles in such facilities are as short as three years. Shipments to mega DCs therefore dominate equipment volumes, making them attractive targets for vendors. However, this also means mega DC owners drive the hardest bargains on price and have significant influence on the roadmap for future technologies. For example, Facebook has put down the challenge to vendors of producing transceiver components at $1 per gigabyte[21] and Microsoft is championing the use of single mode optical fibre in internal DC networks.

3.2.3 The drive for power and cost efficiency

To avoid an energy crisis, next-generation DC technology must offer higher performance without increasing energy consumption. Therefore, every time performance increases (e.g. network speed) energy consumption per unit of performance (e.g. fJ/bit) must reduce at the same rate.

Similar trends are also apparent in equipment cost, with strong downward pressure on cost per unit of performance. This makes it increasingly difficult to recoup the development costs of next-generation devices, in part leading to fragmentation of the market.

However, it is the total energy consumption and total cost of the DC that really counts. Therefore, technologies that are more efficient and produce less heat or can operate at higher temperatures (reducing cooling costs) may provide overall savings, even if they are not individually more efficient.

Cost reduction is also a greater focus when there is no direct link between performance and revenue. Many web-based services, especially in the consumer space, are paid for indirectly, requiring a large user base to attract advertisers. Maintaining and growing a user base requires providing ever-increasing functionality to users but this is only indirectly linked to income as the network grows, making cost reduction a key focus for the operators of DCs behind such services.

3.2.4 The rise of optical technology

Optical fibre and light-based data transmission has long been the technology of choice for long distance communication networks linking continents, countries, cities and metro areas. Copper wires have a limited capacity to carry high speed data — even in connections to the home and cellular mobile towers, traditional copper connections are beginning to limit data capacity. As data rates increase, the distance over which it is essential to move from copper to optical solutions reduces. Data rates inside DCs have now reached the level that optical fibre and associated optical transmitters and receivers are becoming essential for providing connections inside DCs. Optical transceiver capacity within DCs grew by 21% in 2014 and is forecast to grow to >1 petabit per second by 2019, representing a $2.1bn market.[22]

3.2.5 Fragmentation and virtual vertical integration

The drive for cost reduction has begun to cause the DC equipment market to simultaneously fragment and vertically integrate. The biggest DC operators, such as Google, design and manufacture their own DC equipment to meet cost and performance targets. Used exclusively internally, this created the 'white box' market, first for servers and more recently for switches. Most recently this has led to the rise in so called bare metal products,[23] an intermediate solution, with the customer using their own proprietary control software with the supplier focusing on just the bare physical hardware.

More demanding performance at lower prices is also causing fragmentation in product offerings. Previously vendors produced a relatively small range of components and sold them to a large number of different DC customers. Now the market requires a tighter matching of product performance to application. The result is a proliferation of product variants, each optimised to a different application, meaning the volume for any individual variant is reducing despite overall growth. This is having a fundamental impact on the equipment market presenting major challenges and opportunities to equipment vendors.

Figure 4 Overview of impact of DC Market trends on DC hardware

Agile development

Vendors need to be more agile in the development of new products as it becomes harder to gain a return on investment for large-scale lengthy product development cycles.

Open innovation

Agility drives greater openness to leveraging and integrating external innovation, giving a greater role for smaller/newer players.

Product variant proliferation

Products have to be more targeted, with the balance in performance, cost and energy consumption closely matched to the end applications.

New market niches

New markets emerge in niches where the volume-optimised solution compromises a key performance parameter (reliability, security, size, speed, bandwidth, latency).

Technology platforms

Increased emphasis on technology platforms that can support the development of multiple product lines, e.g. silicon photonics.

Reduced barriers change

Barriers to new entrants are reduced as low volume, high value niches emerge but are increased in highest volume applications.

Value chain specialisation

Lower down supply chain drives vendors specialise in one part of the process, e.g. packaging, chip fabrication, building volume over multiple product lines.

4 UK demand

The demand side of the UK DC market is shown in Figure 5, illustrating diverse end users from every aspect of British industry. DCs are vital to manufacturing, used everywhere from inventory management and accounting to complex modelling and production test and measurement. They are similarly important for defence, security and public sector organisations (from the NHS to HMRC) to consumers (exemplified by the BBC iPlayer) and are particularly important in financial services.

To supply these end users there are a wealth of DC providers. Some of these specialise in specific market areas such as financial DCs, others in regional DCs for corporate clients. Many operate more than one DC, with both large-scale campus facilities (e.g. Global Switch in London E14) and geographic disperse facilities (e.g. Onyx). Many are major international companies operating DCs all over the world.
For example, Equinix is one of the largest collocation providers, with ~8% global market share,[24] operating over 100 DCs in 33 cities and 16 countries across the world.

Alongside DC operators are providers of the communications links between DCs and the DC user. These include all of the regular telecommunications operators (e.g. BT) plus specialists (e.g. in radio links for low latency). A number of DC operators also provide communications links for their customers (e.g. C4L), underpinning the importance of strong communications in and out of the DC, although others emphasise their neutrality with respect to communication service providers.

Data Users

Financial	Industrial	Defence/Security	Public Sector	Consumer
Barclays, Morgan Stanley, Goldman Sachs, JP Morgan, UBS and all investment banks	Rolls Royce, GSK, BAE Systems and many more	GCHQ, Police, Boarder security agencies, armed forces	NHS, HMRC, Dept. of Work and Pensions	BBC, Unilever, all major retail groups
Knight Capital, Sun Trading, Jump trading & specialist trading houses				

Demand Side

UK Data Centre Provider	External Communications Network Link
C4L, Cyrus One, Century Link, Equinix, Global Switch, IOmart, Interxion, MDS tech., Microsoft, Node 4, NTT, Onyx, Pulsant, Rackpace, Sungard, Telehouse, UKFast, Virtus etc	Ai Networks, BT, Century Link, Colt Telecom, Custom Connect, C4L, EU Networks, Hibernia, Level 3, Viatel, Venus, Virtual 1

Figure 5 Demand side of UK data centre market from the hardware provider's viewpoint

4.1 UK-specific demand drivers

The DC market exists because, in modern communications, where data is stored and processed can be unrelated to where data is acquired or used. This should make DCs an economically perfect market, where facilities migrate to the lowest cost location. For some global services providers such as Google, this is in part becoming reality, with their latest mega DCs located in colder places with low electrical costs and plenty of land, e.g. Finland.[25]

However, there remain costs in both time and money when moving data. Figure 6 shows a heat map of ~250 collocation DCs in the UK.[26] Even these latest generation multiuser facilities find it beneficial to be near their customers, often based in or near large metropolitan areas.

There are technical reasons for clustering. Long-haul optical fibre networks can carry huge amounts of data but it is cheaper and faster to move data smaller distances. Even when less data volume is concerned, distance can still be an issue. It takes six milliseconds for light to travel from London to Edinburgh and back, 55 milliseconds for the round trip to New York. This is fast, but huge amounts of money can be made (and lost) in the movement of, for example, stock prices in these timescales.

Beyond technicalities, proximity to customers still counts for a lot in building trust and engaging with customers. Whilst companies are getting more comfortable with having data processed remotely, many still like to know it is handled nearby and certainly in the same legal jurisdiction.

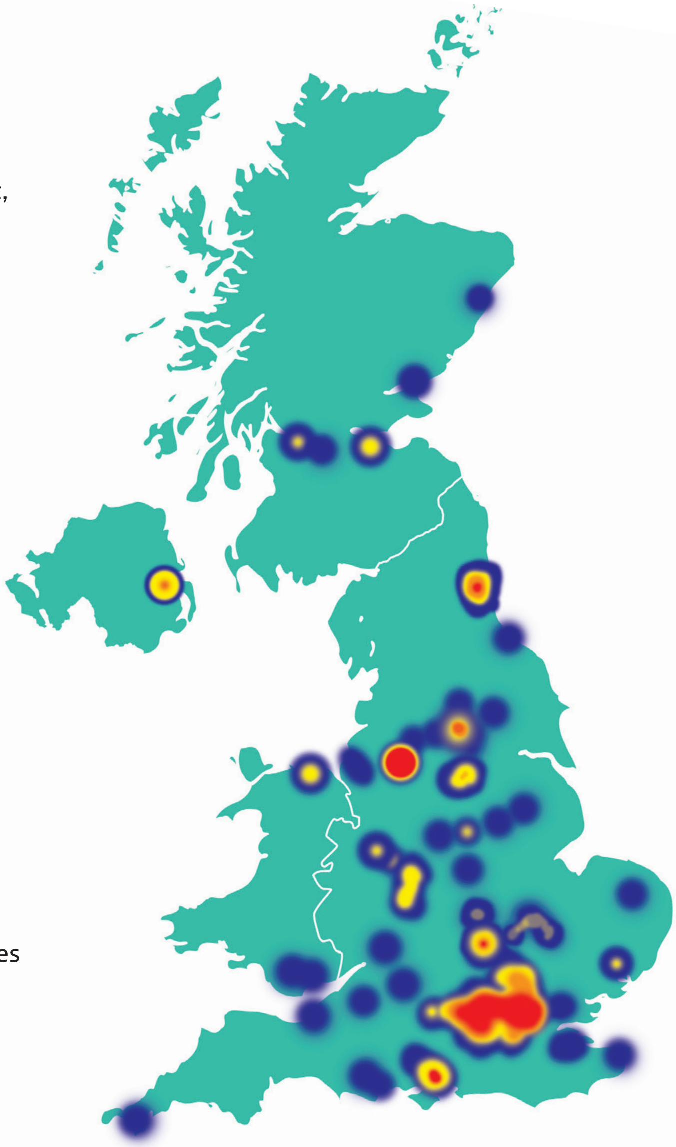


Figure 6 Heat map of UK co-location DCs

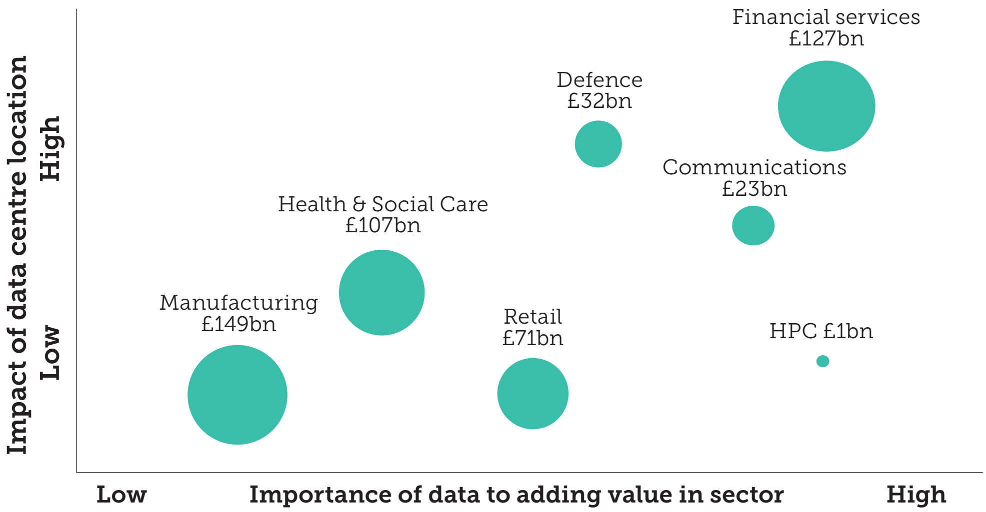


Figure 7 Contribution of data to adding value in key end markets and the importance of data centre location. Bubble size and figure indicate Gross Value Add to the UK economy of different sectors (defence = UK defence spending)

Figure 7 shows the importance of data to a number of key economic sectors in the UK and the relative importance of DC location.[27] Almost all markets have some dependency on data these days. Even those industries on the low side in Figure 7, can — and do — leverage DC functionality, and the importance of data and data analysis is rising. In some cases, such as retail and agriculture, it is rising very quickly. However, not everyone cares where that data is located. For example, when online shopping the consumer has no visibility of where the server and database behind that shopping site is located. We do care about how efficiently our order gets to the warehouse and is despatched but a few milliseconds to transmit that instruction around the world are lost in the overall timescale of physically shipping goods. Hence such services migrate to mega DCs, often located internationally.

Those end markets offering greatest opportunity to UK DCs are the largest markets where data access/analysis and its location are most important. Here financial services dominate. There are other industries such as healthcare where, technically, DC location may be less important but where we are sensitive about having our data held outside the UK. Similarly, security and defence capability increasingly depends on vast amounts of data that, to maintain sovereign capability and ensure the very highest security, must be processed in the UK (for example, in 2015 Microsoft announced a UK hosting of Office 365 for the Ministry of Defence[28]).

The demands driving DCs are therefore not uniform. Although there are many consumer applications where cost, energy and speed are the biggest drivers. Figure 7 shows there are many key sectors where proximity, driven by the time to process/access data and/or security needs, is the highest concern of customers. Such differing needs are driving segmentation in the market. Mega DCs will make up 45% of the market for DC space by 2018, controlled by a few global companies with location influenced more by energy costs than customer location. This still leaves the majority of the market remaining, requiring ~$40bn worth of DC equipment by 2020,[i] meaning these proximity-sensitive applications are not small niches. Clearly some of this market will be addressed by the same 'commodity' products that enter the global mega DCs but even 5% of the non-mega-DC equipment market is worth over $5bn globally.

The UK is not the only country in the world to have hotspots of DC activity that are highly sensitive to local demands. New York, Tokyo, Frankfurt and other financial centres see a clustering of DCs around financial exchanges. Other nations are sensitive to where their citizens' data is held and how it is protected. The latest European Court of Justice ruling has changed the legal basis for the transatlantic transfer of personal data, illustrating how regional attitudes to data protection differ.[29] This means the same factors driving demand for proximity-optimised DC equipment in the UK exist in many locations, providing significant export opportunities for solutions first developed for the UK market.

i Assuming equipment is distributed approximately uniformly across data centre space and a total equipment market of $72bn, as noted in section 4.

5 Financial service sector — special focus

The value of financial securities traded on the London Stock Exchange (LSE) in a single month is ~£100 bn,[30] with the total value of all securities traded on the LSE[31] equivalent to ~14% of global GDP. In addition, 41% of global currency trading takes place in London.[32] These securities are not traded physically but as data. A sector that contributes £124bn in GVA to the UK economy[33] is therefore critically dependent on DC performance.

This analysis focuses on the role of DCs in the secondary market of the trading and resale of financial securities — a value chain illustrated in Figure 8.

In all cases data is critical to buy/sell decisions and the pricing of securities. Some forms of trading (e.g. retail, pension funds or traditional traders) take a long view, assessing the strategic strengths of a company and its prospects for growth, with trading decisions based on a highly diverse range of information and the expert assessment of the trader. In relative terms, the data volume required is large and variable, and the timeliness on which it must be delivered matters — but only on the timescale of human deliberation, i.e. seconds to minutes.

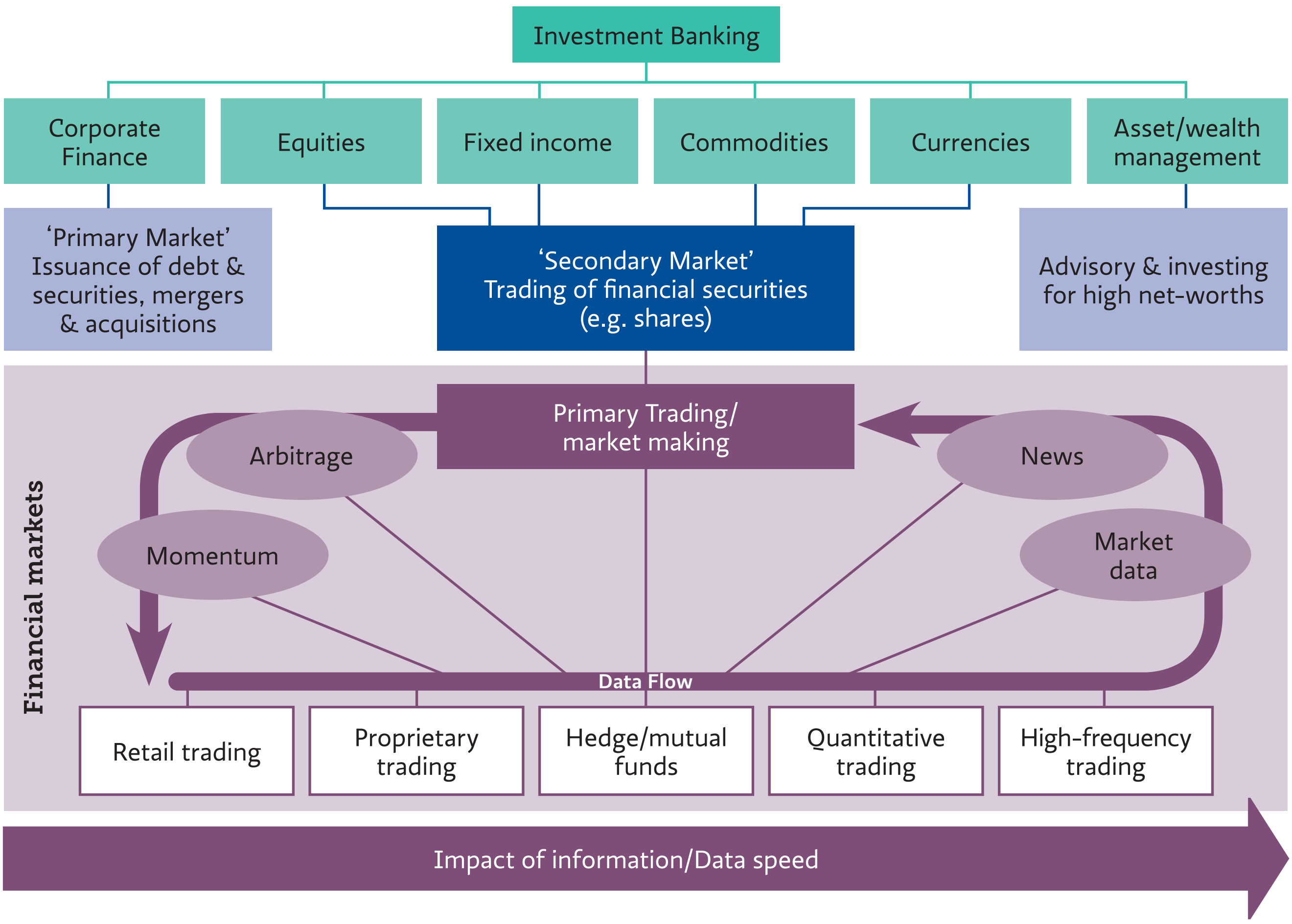


Figure 8 Schematic of financial markets, indicating different types of trading and the importance of the speed of data

In contrast, in high-frequency trading the decision making is mostly automated, embedded in a trading algorithm. The underlying assumption is that other parties, slower to make the same analysis, will also purchase the asset, thus inflating its price and allowing the fastest purchaser to sell at a profit.[ii] Such strategies depend on obtaining live market trading data and its derived information[34] and thus the time to obtain data — down to the last millisecond — is critical.

These two types of trading and the multiple intermediate possibilities are not independent of each other. Trading with a long-term outlook is often facilitated and delivered through high speed trading, which provides significant liquidity in the market.

5.1 The role of the DC in financial trading

The role of DCs in secondary markets is twofold:

1. To act as the infrastructure on which financial institutions trade securities. At the heart of every securities exchange is an order-matching engine where algorithms (depending upon the type of trade executed) match buyers and sellers.[35] The matching of trades at the LSE has been completely electronic since 1986,[36] meaning modern trades are completed on a computer server in a DC based in, for example, Basildon[37] — not on a trading floor in London.

2. To provide the information on which trading decisions are made on, e.g. quotes, volumes, market activity and trends. While there are several feed types for accessing live market data, there are broadly two ways in which data can be accessed: via a direct feed from the matching engine or through the Securities Information Processor (SIP).

The total quantity of data required to complete security trades is not large. The 200 million trades completed on the LSE each year equate to only ~200 gigabytes of data,[iii] no more than the capacity of a small hard drive.

However, the value of that data is extreme. Considering only the LSE UK stock trading order book, every digital one or zero transmitted in trading is worth ~£6 per bit or £57bn per gigabyte. If it were moved physically, this would make a very valuable memory stick!

Figure 9 Illustration of the monthly data volume of the UK stock order book on LSE

In contrast, the data traffic generated in providing information for making trading decisions is huge. Placing a trade is the end result of asking many questions from many places. One of the most effective methods of getting market data is to request a quotation from an exchange. The rise of high-frequency trading strategies has seen a huge rise in quotation requests, with high speed algorithms sending out millions of such requests every second to multiple exchanges. The result is increased computing requirements in the exchange-matching engine and an explosive growth in the volume of data initiated by obtaining quotes from multiple exchanges. In the US, the capacity for Consolidated Quote Systems across all exchanges has been in excess of one million quotes per second since 2011[38] with similar figures for the UK. Again, assuming each quote requires a one line, 100 byte text string to be transmitted and received, this amounts to five terabytes of data per day or one petabyte per year.

The volume of quotation data is equivalent to almost 1% of all UK mobile data traffic[39] and becomes a significant fraction of the load on the network infrastructure. Not only does this drive demand for higher-capacity, low latency links — as the return time to request a quotation and receive a response can be critical to the trading decision — it also causes exchange DCs to cluster around key access points on the core fibre network and where local network capacity is greatest.

ii Excluding market making and some arbitrage strategies, while the predictive strategies employed by some may be different (for example, quantitative, technical, and fundamental analysis)

iii Assuming each trade requires the transfer of one line of text at 100 bytes per line, ten times around the system.

5.2 Financial trading drivers impacting DCs

5.2.1 Trade execution speed:

The impact of trading speed varies according to trading strategy. High-frequency traders looking to engage in forms of arbitrage or take advantage of an exchange's liquidity rebating system will have a much higher demand for high speed data. As of December 2012, high-frequency trading firms were active in approximately 27% of the trading volume in UK-listed equities.[40]

However, the ability to trade faster also means more trades can be completed per unit of time. This encourages the lowering of financial spreads, making markets more efficient, reducing everyone's trading costs. Thus competition for the fastest trade execution speed remains an ongoing trend throughout the industry and is a significant driver in the development of a new trading infrastructure.[41]

5.2.2 Data Latency

The largest factor affecting the overall speed of trading is the communication route between trading parties. Whilst the design of the software and the servers on which matching engines and trading algorithms also has impact,[42] trading cannot take place faster than the information flows. Importantly, this is not the volume of data in megabytes per second — it is the time data takes to get from a to b, known as 'latency' and measured in milliseconds.

Thus there has been an increase in demand for low latency links in the past five years, with many DCs targeting financial industry clients marketing the latency of links from their location to key exchanges. Firms and institutions trading with high-frequency strategies will have the greatest demand for such links as it is a primary factor in their performance. Examples of such specialised firms include Knight Capital Group, Sun Trading and Jump Trading. However, the secondary impact on market efficiency means low latency trading systems and links are used by nearly all major financial institutions for making markets and/or proprietary trading in highly liquid markets.

Key Drivers of Change in Financial Trading DC's

- **Execution speed**
- **Data speed/latency**
- **Location between exchanges**
- **High speed data as a service**
- **Quote volumes**
- **Latency volitility**
- **Regulation and time stamping**

Figure 10 Key drivers of change in financial trading DCs

5.2.3 Location of the exchange

The move to electronic trading has seen the heart of the financial exchange move from the physical trading floor to the DC. Alongside this there has been a boom in the number of exchanges enabled by the MiFID (Markets in Financial Instruments Directive) in 2007 which paved the way for the decentralisation of trading venues. There are currently 154 Market Identification Codes (MICs) for potential exchanges within London where the transaction of specific financial securities can take place.[iv] As a result of the need to accurately price assets across multiple exchanges, this has meant that the importance placed upon low latency systems has increased.

As latency is linearly dependent on distance, there is a strong incentive to collocate high-frequency trading systems within the same DC as the exchange or get them as close as possible. Hence exchanges have a habit of clustering around each other, i.e. the distance between DCs active in trading between multiple exchanges is normally a maximum of 30–35 miles.[43] This is why there are so many DCs clustered around London (Figure 6) and why financial trading is the most important proximity-sensitive DC market in the UK.

5.2.4 High speed market data as a service

In the early days of high speed trading there was a rush to leverage low latency links to exchanges to get the fastest market information. However, recently there has been a rise in the provision of low latency market information as a subscription service to compliment data generated directly from quotations. Many of the exchanges that allow for the presence of high-frequency traders will sell subscriptions to live data feeds, creating a significant source of income for the exchange.

If one provider can deliver this information to many subscribers, e.g. within one DC, it can be delivered over a single low latency link. This reduces demand for the proliferation of low latency links — at least to access market information, if not for the actual quotation and placing of trades. However, a data supplier needs to appeal to as many subscribers as possible and be flexible to their customers' data requirements. This increases the data capacity required on such links, which is relatively limited for the current lowest latency radio and microwave systems.

5.2.5 Latency volatility and monitoring

The consistency of latency data is essential for the accurate running and development of trading algorithms — in extreme circumstances variations risk turning profit-making strategies into loss-making ones. Monitoring systems throughout the trading process helps protect against such risks, ensures consistency in trade execution prices and allows for the development of overall faster trading routes. Azul Systems Vice President of Technology and Chief Technical Officer Gil Tene has stated: "Being fast consistently and being able to predict consistency is just as important as being fast on its own."[44]

The measurement of trade execution and quotation times and their volatility is a major trend within the investment banking industry. Globally many of the larger exchanges now offer latency monitoring for their matching engines[45] but the sophistication is yet to reach a level where all of the major routes can be monitored in tandem.

Latency monitoring is especially important for the accurate testing of potential strategies. Most new algorithms are tested on simulated markets before being released but the accuracy of the simulation requires matching the modelled latency with that encountered in the real world.

iv Excluding data centres working in conjunction with the operation of clearing houses and including open access Recognised Investment Exchanges and those with restricted access (Dark Pools). http://www.iotafinance.com/en/ISO-10383-Market-Identification-Codes-MIC.html

5.2.6 Time stamping

Time stamping requires embedding data on precisely when a trade took place. With the expected application of the Markets in Financial Instruments Directive II (MiFID II) Act across the European Union in January 2017, the accurate time stamping of trades is expected to become more significant.[46] Currently the time stamps applied to data can be contradictory due to small difference in the reference clocks used between different DCs and parts of the network. An article published by the UK's National Physical Laboratory (NPL) states: "in some cases, data can appear to travel backwards in time when sent from one location to another".[47]

To provide accurate time stamps MiFID II will require firms to synchronise their DC servers with Coordinated Universal Time (UTC). Trades deemed to be high frequency in nature will need to be time stamped at microsecond intervals, with a maximum divergence of 100 microseconds from UTC.[48] Obtaining such synchronisation between DCs is not trivial, considering that it takes more than 100 microseconds for data to travel 20km along the optical fibre, meaning variation in distances from the reference time standard cause variations in the time stamp.

Improved time standards are an important part of the solution. NPL has been leading the way here, providing NPLtime — a UTC traceable time stamping service to trading organisations.[47] This provides a basis for further network and latency monitoring solutions.

> ***Circuit breakers:*** *any measure used by exchanges during large sell offs in markets to prevent further panic selling. e.g. if a stock falls by >10% in a five-minute period, trading of that stock is temporarily paused.*
>
> ***Arbitrage:*** *Taking advantage of a price differential between related financial securities on different exchanges.*

5.2.7 Regulatory change

The potential impact of regulation on high frequency trading is significant,[49] especially on those using trading strategies in arbitrage or electronic front running between exchanges.

In conjunction with this, there is debate as to whether providing live market data on a subscription basis (see section 5.2.3) to only some members of the secondary market community creates an imbalance between participants.[50] However, the steps being taken through MiFID II to gradually implement an improved level of transparency within the lower latency levels of trading, mean that the overall concerns amongst institutions and firms has subsided recently with regards to live data subscriptions.

Further regulatory change could be expected within the next five to ten years in the implementation of additional circuit breakers in the trading of equities and derivatives. Individually, such circuit breakers only have limited impact on high frequency trading as their constraints are rapidly built into the trading algorithms. However, there is little information on the efficacy of circuit breakers across a market made up of multiple exchanges.[51] Given the trend for high frequency trading to use quotes across multiple exchanges and the proliferation in exchanges, further regulatory interest in the area is likely.

5.2.8 Risk and volatility protection

In financial markets the amount of low latency data required in normal trading may be moderately high but in highly turbulent markets, or when volumes spike in response to external events, limited network capacity can compound — or even increase — the volatility of the market. In the 2010 'flash crash', lag in the delivery of market data created a sudden increase in trading volumes and is thought to have compounded the scale of the crash.

Having more low latency links with much higher capacity reduces the risk of lag-induced pricing variability, helping to alleviate the potential of technology-induced market events.

6 UK capability — supply side

The supply side of the UK DC equipment market is illustrated in Figure 11.

Equipment systems

Network	Server	Storage	Power & Cooling
Polartis, Cisco, HP, Arista, Avaya, Brocade, Dell, Extreme, Juniper, Networks, Huawei, Lenovo First Mile Networks	HP, IBM, Oracle, Cisco, Dell, NEC, Fujitsu	EMC, HP, Oracle, NetApp, Seagate (Xyratex)	Schneider Electric, Emerson, Eaton, Geist, Rittal

Components

Transcelvers	Packaging & Test	Semi-conductors & sub-component
• **Oclaro**, **Huawei**, **Fujitsu**, Finisar, JDSU, Infinera, Cisco, Ciena, Alcatel-Lucent, Neophotonics, Sumitomo electric, **Effect**, **BB photonics**, **TeraOpta**, **PureLiFi**, **Rockley Photonics**	• Optocap, Bay photonics, Yelo	• CST, IQE, Seagate, Oclaro, aXenic, Gooch & Housego

World Leading UK Research Base

Communications		High performance computing
• University of Aston	• University Nottingham	• Hartree Centre
• University of Bristol	• Queens University Belfast	• Archer
• University College London (UCL)	• University of Sheffield	• Hector
• University of Southampton	• Cambridge University	• Core
		• HPC Wales

Figure 11 UK data centre equipment supply chain. Companies with a significant UK presence are in bold.

6.1 Equipment vendors

DCs require both hardware and software and, although trends to virtualisation have increased the role of software, ~77% of the market by revenue remained with hardware in 2015.[52] Expenditure is evenly split between networking and server equipment with slightly less spent on storage. In the UK, almost all of this equipment is currently imported, as shown in Figure 12, with HP, Cisco and Dell the leading providers. However, different vendors lead in different types of equipment. Cisco dominates the market for DC networking equipment by a substantial margin, with over 50% market share in some Ethernet switches,[53] whilst HP has the dominant position in the server market.[54]

A notable number of the leading players host significant development centres in the UK, including Huawei, Fujitsu, HP and Seagate. The UK also has a number of specialist network equipment suppliers, e.g. Polartis supplying optical switches and Geist and Rittal supplying power solutions — all supported by a number of specialist civil engineering firms involved in DC construction across Europe.

UK data equipment suppliers

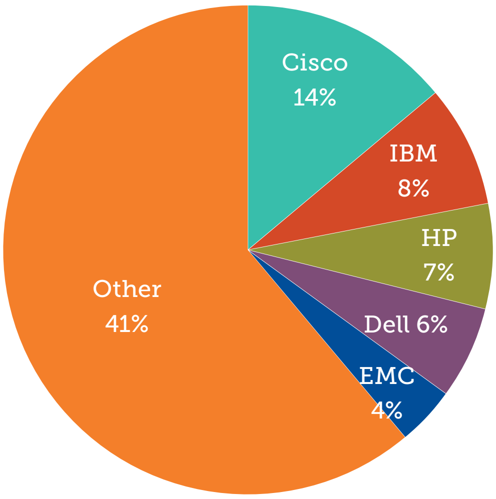


Figure 12 Current suppliers of UK data centre equipment (source Catdor 2014).

6.2 Component suppliers

At the component level the UK has multiple suppliers, especially in DC network equipment components and storage. These range from the latest transceivers manufactured by Oclaro in Caswell to semiconductor components manufactured at wafer scale (e.g aXenic, Oclaro and CST) to semiconductor wafers from IQE. 30% of the world's read/write heads for hard drives used in DCs start life at Seagate's manufacturing site in Springtown, Northern Ireland.

The strength of the UK in network and storage system components is not reflected on the server side. Currently Intel holds ~95% of the market for DC server processors[55] and the UK is not a base for server processor design nor silicon manufacture (the exception is in low power processors).

The root cause of this difference is in the type of semiconductor used. Networking equipment frequently uses compound semiconductors,[v] in which the UK has considerable design and manufacturing capability (and in which a new Catapult centre was announced in 2016). Processors and memory are currently based on silicon semiconductors, manufactured in a few large-scale foundries outside the UK.

The UK also maintains significant expertise in ultra-high-speed silicon design, e.g. at Fujitsu Basingstoke. Such designs are particularly important in the highest speed networking components where the high speed processing is used before and after data is transferred to the optical domain for transmission.

Figure 13 Oclaro 100G QSFP28 CLR4 Transceiver (source Oclaro)

v Compound semiconductors are critical for the conversion of light to electricity, and vice-versa, and are at the core of any optical communications link. Such conversion is not possible in silicon and thus modern communications combines high speed silicon electronics with compound semiconductors and optical fibres.

6.3 Research base

The UK has a particularly strong research base in technologies that are critical to the development of next-generation DCs. Much of this expertise has been built up over four decades of research into optical communications and data science. As illustrated in Figure 14, this expertise is embedded in multiple universities across the UK.

As a reflection of the UK's leading position in communications research, the Engineering and Physical Sciences Research Council (EPSRC) has invested substantially in the area over many decades. EPSRC is currently supporting at least 111 grants in the broad area of communications with over £158m invested.[56] UK research expertise extends throughout the technologies from optical fibre and compound semiconductors to integrated photonics, data storage, high speed electronics, encoding, data transfer protocols and magnetics. This research also extends throughout the value chain from next-generation materials to critical components to systems.

The UK also has significant expertise in high performance computing, including multiple high performance computing facilities in universities (shown in Figure 11), the Hartree Centre and a new £97m super computer at the Met Office.[57] Supercomputing facilities have much in common with high-end DCs — with high speed, low latency networking being key to linking the thousands of computer processors they contain. There is also a move to deploy more optical technology to link the processors, opening opportunities to the UK's optical communications knowledge base.

One of the key challenges in supercomputing is how to formulate complex problems to make best use of their computing power. This is increasingly an area of UK expertise and one that can be applied to the processing core of DCs, such as the matching engines in financial exchanges, if the relevant networking, processing architecture and user communities are brought together.

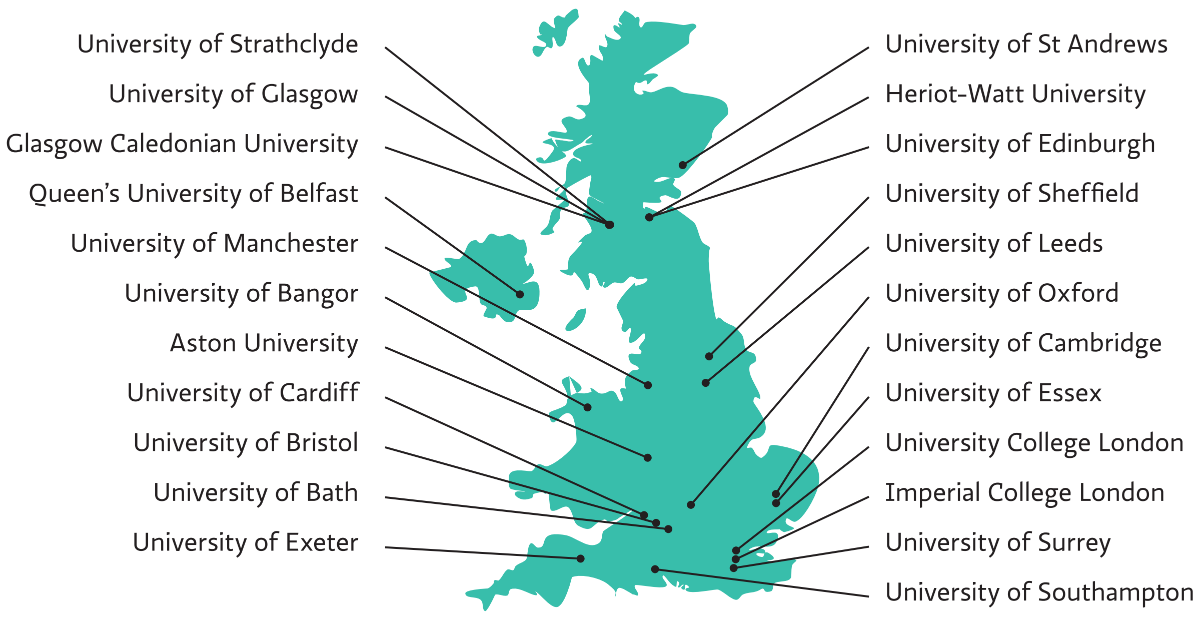


Figure 14 Key academic centres of data communications research in the UK

7 UK supply-side opportunities

The increasing fragmentation of the DC equipment product offerings and the strong demand for localised DCs in the UK, especially from financial services, gives rise to two divergent streams of opportunities, as illustrated in Figure 15.

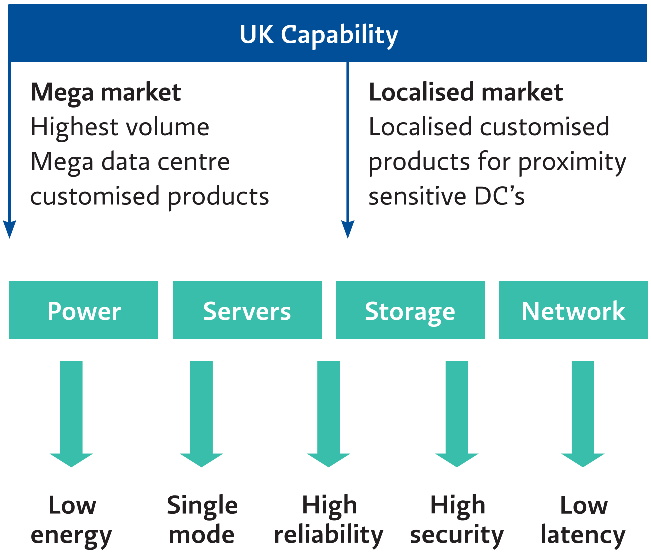


Figure 15 Divergent supply-side opportunities for data centre equipment and services manufactured and/or designed in the UK.

7.1 Mega DC opportunities

There are opportunities in supplying storage, network and power solutions to mega DCs globally. This is a high volume, focused market where cost and energy per unit of performance are absolutely key. The market is also extremely competitive, attracting all global IT equipment suppliers, significantly reducing the opportunity for making sustainable high margins. Additionally, few if any of these mega DCs are located in the UK due to the price of land and energy, meaning few local mega DC customers.

In the storage segment (via Seagate) and network equipment (via Oclaro) the UK has companies of significant scale and globally leading capability already addressing opportunities in mega DCs. There are also a number of start-ups, e.g. BB Photonics and Rockley Photonics, developing solutions.

The UK also has world-leading design capability in low energy computing at ARM. Pioneered for mobile devices, applying this expertise to the most energy-sensitive DC computing requirements could have a significant impact.[58]

7.2 Location-sensitive DC opportunities

In contrast, fragmentation of the DC equipment market and strong demand for localised DCs provides a new generation of opportunities for products targeted at specialist, high performance, proximity-sensitive DCs.

Products that meet the low cost, high volume needs of mega DCs will not meet the needs of specialist, high performance, proximity-sensitive DCs. The days of one DC product working for all applications are fading. Any surplus functionality, reliability or security will inevitably be engineered out of mega DC products, making room for the high value, higher engineered products in which UK electronics and photonics manufacturing excels.

This is not an established market but one that is rapidly emerging due to trends in DCs and the divergent needs of users, providing the opportunity for the UK to benefit from the start. It is also not a market that attracts significant analysis because it is geographically localised. However, it does fit well with UK capability — as a high value, high performance niche that builds upon a significant local knowledge base and where there are high impact UK end users.

As befits any new emerging market, there are few suppliers who would identify existing products specifically engineered for location-sensitive DCs. Current demand is being met from existing international suppliers by generic equipment. However, UK DCs are already selling services based on location-sensitive parameters such as latency, driving purchasers to look for improvements in these areas through better equipment. UK suppliers who focus on meeting these requirements and work with end users to understand the impact it has on them (e.g. enhancing trading volumes and profits) will be able to differentiate their products and gain market share.

Location-sensitive applications will have lower volume demands, a higher focus on performance and local customers, and in some cases (e.g. high speed trading) a more direct link between performance and income. This creates opportunities for many more UK companies to enter the DC equipment market if they can be connected to local customers and understand their specific needs. There may also be more than one location-optimised market, depending on the balance between latency (e.g. for finance users) and security (e.g. for health, defence/security users). It is notable that the ability to securely make real-time decisions is a common feature for all of these markets, leading to common technology drivers despite the diversity of proximity-sensitive end users.

The extensive UK academic knowledge base identified in section 6.3 is well positioned to supply solutions for specialist localised DCs. The UK has pioneered methods of expanding optical communications capacity in the core network. Whilst challenges in this domain remain, the market has matured and, unlike the 14% growth in optical DC networking equipment,[59] revenues in long haul and access equipment are flat to declining,[60] with no system suppliers remaining in the UK. Capacity and latency are closely interrelated and the knowledge base built up developing the former could have significant impact if applied and connected to the emerging needs of low latency and other location-sensitive DC requirements.

7.3 Specific UK technology opportunities

Some specific UK technology opportunities, especially those related to proximity-sensitive DCs, are indicated in Figure 16.

Low latency high capacity networks	Latency monitoring / measurement	High speed exchange matching engines	Enhanced security networks	High speed integrated photonics	High speed high capacity stroage
· Optical switching · Low latency, high capacity encoding formats · Hollow core optical fibre	· Leverage time standards · Real time in-service monitoring	· High performance computing	· Latency optimised encryption	· Compound semi-conductor / silicon integration · On board, close to processor transceivers	· Compound semi-conductor / silicon integration · On board, close to processor transceivers

Figure 16 Specific technology opportunities of relevance to proximity-sensitive data centres.

Many of the technology opportunities in Figure 16 relate to latency, as the time to exchange information is a key factor, driving localisation and the clustering of DCs. However, local data capacity, including low latency network and processing capacity, are still vital components and solutions to deliver higher network capacity over long distances may not be appropriate when they compromise latency. Security is also high on the requirement list for many location-sensitive applications — but again the priority is delivering security without delaying data delivery.

Adding encryption for security is not without performance costs. It takes time to encrypt and decrypt, increasing the time to transfer data. This can be a particular problem for securely transferring high bandwidth data such as video. Similarly, methods of maximising bandwidth often involve complex data encoding and error correction. This is most often performed by high speed digital processing in the transceivers at either end of a communications link. However, it also slows the transmission of time-critical data, causing the lag between input and remote system response bemoaned by players of computer games and other real-time network users (e.g. remote surgery). Therefore some DC hardware is now sold without forward error correction for time-critical, low lag/latency applications.

7.4 Economic impact

Exploiting these opportunities in the UK could have a very significant economic impact. Just a 10% share of the UK DC equipment market would be worth £4bn and have a direct impact on the balance of trade, as much of this equipment is currently imported.

However, this is eclipsed by the potential impact on the financial services sector. As DC equipment currently deployed in London is generic and links to next-generation technology are poor, there is little from a hardware perspective to keep current trading volumes in London other than the clustering effect. Should better DC facilities become available at other trading centres, there is the real risk that some forms of trading, e.g. high speed trading and FX trading, could move offshore, putting at risk a significant fraction of the £21bn the UK receives in tax receipts from the financial sector and the 2.1m jobs in the financial services and related industries.[61] This risk is more acute as there are ~£2.2 trillion of foreign assets under management in the UK (35% of the total assets under UK management[62]), which have no physical link to the UK.

On the flipside, if the financial services sector and other proximity-sensitive data can be connected to next-generation UK technology it would give businesses a physical, hardware-based reason to be in the UK. Whilst others could deploy such equipment in the future, it would give London's financial sector a hardware-based, first-mover advantage. This could attract more financial business to the UK, in turn feeding more local demand for customised hardware, creating a positive upward demand spiral. This would create a fundamental link between the previously separate financial services sector and the UK manufacturing sector — to the benefit of all.

Although the greatest economic impact for the UK is likely to be within the financial services sector, there is significant additional potential impact in defence and security, especially areas requiring high security and/or the real-time assessment of data. There could also be impact in other areas where time-to-decision is critical, e.g. remote healthcare.

8 Barriers

The barriers to market penetration in DC equipment are changing rapidly and increasingly differ depending of the type of DC targeted.

8.1 Mega DC equipment barriers

There are a small number of high profile global customers with extensive purchasing power demanding high volumes at low costs with exacting performance requirements and rapid product development cycles. Even for billion-dollar companies, entering, supplying and maintaining a product pipeline into these markets has been difficult. Global powerhouses such as Intel have looked at new architectures built around supplying complete racks rather than individual servers to secure greater value and return.

This does not mean the UK should abandon these markets to others. The rapid development time cycles in this market make it highly receptive to buying in new technology solutions. The UK should focus its investment on the underpinning and enabling platform technologies. Identifying in detail what those underpinning technologies are requires further consultation and collaboration amongst the following communities: silicon photonics, compound semiconductors and nano/metamaterials.

To have impact, innovations in these areas need to be rapidly scaled to volume production. Therefore, manufacturability and fit with volume production throughout the value chain is key. Innovation that is based on a volume-scalable wafer technology but lacks or inhibits volume packaging is unlikely to succeed.

8.2 Localised DC equipment barriers

There are many drivers that favour the emergence of unique solutions for this sector but significant and very different obstacles remain, as indicated in Figure 17. The biggest barrier is the lack of connection between the end user and the hardware innovators and the associated lack of understanding of the advantage new technologies can bring to the end user.

Barriers					
Link tech performance to financial return	Confidentiality if financial/ security models	Monitoring of tech performance	Lack of common language	Complexity of who specifies what	Regulation impact/change

Figure 17 Barriers to entering and developing solutions for location sensitive data centres typified by financial services but also applicable to defence, security and other location sensitive data centres.

The time to gather data, make a decision and act on it is determined not just by the optical fibre used but how the data is processed, decisions are made, signals are encoded and how the network is constructed, requiring input from multiple players. In high-speed trading the detailed algorithms used are also a closely guarded secret, as are the decision-making processes in other proximity-sensitive markets such as security and surveillance. The impact of a technical improvement, e.g. on reduced link latency, is therefore hard to judge: to some it may be significant, to others irrelevant. It is certainly information that is unlikely to be shared, making it difficult for innovators to quantify their impact.

The introduction of regulatory framework in 2007 — MiFID — the fragmentation of secondary market activity and proliferation in the number of financial exchanges[63] has also created an environment where there are few individuals who have the understanding to bridge the gap between technological advances and the areas they may have impact in the finance industry.[64]

In other markets, end users often seek out technical innovations that would give them a market edge, reaching into the innovation and knowledge base for future competitive advantage. In financial trading, the value of data is so significant, small differences in performance can yield major gains but degradations can lead to substantial losses, resulting in a cautious approach and a bias towards standard solutions. Coupled with the aforementioned lack of deep technical understanding, this fosters the classic "nobody ever got fired for buying IBM" approach to equipping DCs. This, in combination with an industry culture of infrastructure secrecy, means that the uptake of new technology is slow and there is little direct investment in next-generation technology from those who might benefit most from its early adoption.

To accelerate advanced technology deployment, its impact on performance needs to be quantified. A lack of independent characterisation techniques for parameters that matter to location-sensitive DCs, such as latency, remains a barrier to the development of new solutions for these markets. Without parallel development in measurement and characterisation, new DC hardware cannot be differentiated from existing generic solutions.

The DC user and operator relationship can also present barriers. Where equipment is owned by the client and hosted by the DC, the equipment owner might be assumed to take the lead on adopting hardware innovation but this can be constrained by the capability of the DC host. However, DC operators often differentiate themselves on their connectivity, security, power and cooling capacity and therefore could drive the earlier adoption of innovations before they are required by the end user.

In financial markets there are also risks in the implementation of changes to the existing infrastructure. For example, low latency trading environments may magnify price volatility due to the increased volume of trades per unit time. Moreover, an unstructured upgrade of the secondary market infrastructure would allow the short-term progression of minimally legislated and occasionally sensitive trading strategies that are active in certain stock exchanges.[64]

9 Recommended interventions

The UK has many of the key elements necessary to be a key global player in the DC equipment market — major end users, a strong research base, a billion-pound specialist local market, core supplier capability and capacity for substantial supplier growth. However, the market has failed to generate the necessary links between these core elements to create a market-driven development and uptake of UK technology.

Resolving this market failure requires bringing the relevant parties together, as illustrated in Figure 18, so they can create a common understanding of the opportunity. The complexity of the supply chain landscape and the importance of key but highly time-constrained end users in the financial sector requires a structured approach. This includes:

1) The identification of long-term enabling technologies that are key to impacting mega DCs through a workshop involving existing technology developers. This should focus on the UK's potential to make an impact within the global DC market and the key technology platforms where the UK has world-leading capability. These include silicon photonics, compound semiconductors, energy-efficient computing and DC/computing architecture. Highlighting this capability should help drive inward investment and flag where research and development investment is most likely to have a long-term impact within global mega DC markets.

2) Bringing together technical decision makers in high speed trading and technology innovators to develop a common impact and technology roadmap linking UK technology with advances in high speed trading. Given that it is unclear whether the highest impact will be through providing more market information faster and/or providing lower or more consistent latency access to the exchange, this should include those responsible for DC infrastructure at the UK financial exchanges and those responsible for providing real-time market information. For maximum benefit to the UK economy, targeting the largest exchange providers in the UK is logical, i.e. LSE Group, BATS Chi-X Europe and Turquoise (see Appendix 1).

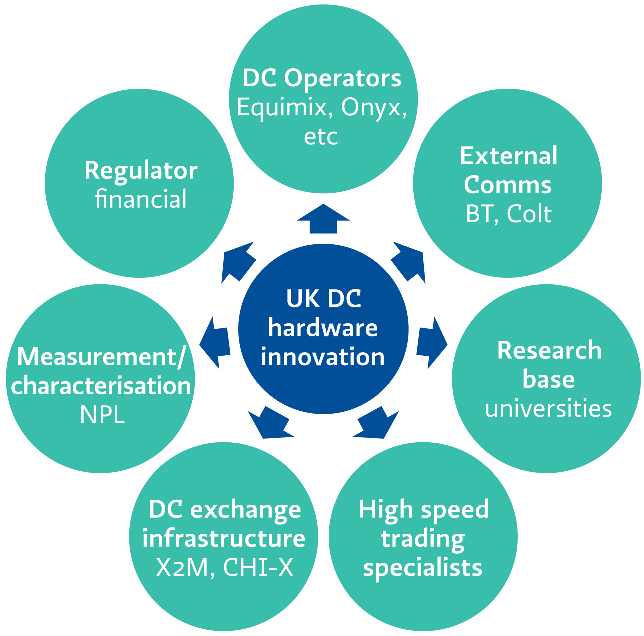


Figure 18 Parties required to be brought together to maximise UK data centre equipment development, uptake and impact

3) Bringing together financial regulatory authorities, measurement experts (e.g. NPL) and technology developers to understand positive and negative impacts, including regulation and risk management of next-generation DCs and high speed communications technologies.

4) Bringing together other location-sensitive DC users from government, defence and security, public services and their DC providers to determine common requirements that may not be met by the development of low cost technologies for mega DCs. The critical component outcome will be the identification of new niches (and their detailed definition) that are separate from the future needs of mega DC operators.

10 Conclusion

DC equipment is a major international and domestic market worth over $100bn globally, with the UK being the leading market in Europe, buying over £20bn in equipment annually.

Whilst this market has to date been dominated by global players, the DC equipment market is increasingly fragmenting as it matures. The needs of mega DCs for consumer, large scale, time-less-critical and cloud applications are driving high demand for improvements in cost, bandwidth and energy performance. There are already UK companies successfully deploying solutions into such DCs, often as part of an international supply chain. The hunger for rapid innovation also makes the market open to new innovations developed by the UK's globally leading innovation base, especially in optical communications, storage and energy-efficient computing — as long as they can meet the challenge of rapid large-scale deployment and short lifecycles.

Mega DCs will migrate to locations offering the lowest energy, cooling and space costs in what is already a very globalised market. However, although they grab the most headlines, mega DCs represent <50% of the equipment market. Many more DC customers are sensitive about the location of their DCs. For the UK, by far the most important of these proximity-sensitive customers is the financial services industry, in particular the trading of financial securities. There are multiple financial exchanges in and around London, each housed in a DC and trading trillions of pounds of assets annually. The data volumes for completing this trading volume are not significant but the rise of high speed trading and the way the market is interrogated to get the best prices drives demand for substantial local data volumes, extremely low latency communications, high speed processing and system monitoring.

As these and other DC applications mature, the market for DC equipment is fragmenting, with optimised solutions emerging for differing applications.
The proximity-sensitive DC market represents a significant opportunity for the UK, as London provides globally leading end user demand. The UK's innovation base is also well positioned to provide solutions, with world-leading capability at multiple research institutes in optical communications, optical fibre, data storage and high performance computing. The capacity to adopt innovations and deploy them is also present throughout the supply chain — from DC providers to equipment manufacturers.

The largest barrier to market, however, remains a lack of understanding on all sides of what UK data hardware could deliver to the financial services and other proximity-sensitive DC segments in multiple business-critical areas. Potential benefits include enhanced financial performance, reduced risk, reduced cost of deployment and increased ease of deployment. Very few individuals can translate between the financial metrics that drive trading and the underlying hardware capability. Whilst there are structural reasons for this, bringing these communities together would enable the UK's most valuable data users to drive the development of hardware solutions that would give London a sustainable competitive advantage as the first adopter of next-generation, low latency, proximity-sensitive DC solutions.

Without developing these links within the UK, there is a significant risk that other global financial trading centres will develop improved DC hardware first, risking the migration of financial trading to outside the UK. However, if successful, a real and effective link can be made between the UK's eminent financial services sector and its hardware innovation and manufacturing base.

11 Appendix 1 – Financial sector key players

Whilst the identification of all relevant contacts in the finance sector and DCs is outside the scope of this report, the following table gives some examples.

Table 1 Key players and organisations from the financial sector and associate DCs.

Role	Organisation
Business development manager	BATS Chi-X Europe
	X2M DC infrastructure department of the LSE[65]
	Turquoise
Investment banking market and client connectivity	LSE Group
Infrastructure project manager	
Market analysts of UK DCs	Tariff Consultancy Ltd - http://www.telecomspricing.com
	Gartner Data Center, Infrastructure and Operations Management Summit www.gartner.com/events/emea/data-center

12 Appendix 2 – key sources

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13 Acknowledgements and contact details

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