How Current Technology Trends are Empowering Us All to Drive Innovation

Ben Langham

London Underground AP JNP Escalator Services,
Frank Pick House, Bollo Lane, Acton, London W3 8RP
ben.langham@tubelines.com

Keywords: Innovation, London Underground, escalators, lifts, maintenance, technology, web

Abstract. Recent technological trends have given those outside the Information Technology industry access to increasingly sophisticated products and the ability to contribute to their development. These trends, such as cloud computing, democratisation of the web and ubiquitous embedded devices are breaking down the separation between creator and end user. One effect of this is the ability for users to drive the development of their own innovative solutions, informed by essential domain knowledge. This paper explores the implications of this on the maintenance of lifts and escalators and the associated challenges and risks. Some of the ways in which these opportunities are improving the maintenance of London Underground's assets shall also be presented. These include a web-based solution which integrates multiple data sources to facilitate effective maintenance and asset management decisions.

1 INTRODUCTION

The last decade has seen technological changes that have significantly changed the way we live our lives. Forty years on from co-founder of Intel, Gordon Moore's observation that computer processor speed was doubling every two years [1], this exponential trend has continued. The reduction in size and cost of processing power, coupled with improvements in networking technology and transmission speeds opens up many possibilities. The Internet is evolving and growing, through global collaboration and the sharing of knowledge and ideas, with many developments expected in the future.

Today, it is not only those with an in-depth understanding of programming or computer science theory who can actively contribute to the development of advanced technical solutions. Improvements in hardware and software, plus the availability of cloud computing, have put tools previously reserved for specialists in the hands of small businesses and individuals. User-friendly interfaces provide an abstract layer around complex tools, and mobile devices and modern web browsers enable the deployment of applications to multiple users with minimal investment.

London Underground is increasingly looking for ways to make cost savings and improve efficiency. Being a large public service organisation responsible for a complex and aging transport network, the scope for improvement is significant but so too are the challenges in making changes to existing processes. With growing passenger numbers placing more demand on the service and the introduction of a 24-hour operation at weekends reducing the number of hours available for maintenance, the optimisation of resources is vital. One of the areas in which London Underground is innovating is in the maintenance of its assets. Extracting value from data and making it available to the right people in a useful format is possible due to the capabilities now afforded by recent developments in technology, which, if applied appropriately, will enable maintenance to take an increasingly predictive, condition-based approach and optimise the use of available resources.

This paper outlines the main technological trends influencing our ability to drive innovation as end users, from prototyping of connected devices to the development and deployment of mobile software solutions. Two examples of innovations in lift and escalator maintenance at London Underground, which have been made possible by these trends, shall be presented. In each case a specific problem was identified which existing systems were not capable of solving, presenting an opportunity to develop a cost-effective solution with the tools and technologies available.

2 INNOVATION

To innovate is to make changes in something established, especially by introducing new methods, ideas, or products [2]. As well as the use of new technology, innovation can also involve applying existing technologies in new ways.

It has been understood for some time that innovation can come from different sources, and that each can have contrasting functional relationships defining the benefits to be obtained from the innovation [3]. These sources can include users (both firms and individuals), product manufacturers and distributers. It is also suggested that the interests of the user and the producer are misaligned. Where the former aim to meet their exact requirements, the latter tend to generalise solutions or adapt their own existing products to maximise profits [4].

In many fields, product users are the major sources of innovation, and research shows that there are advantages to users with unique needs in developing products for themselves [3]. The context in which the innovation sits, and the associated domain knowledge and expertise, are essential for a product to meet user requirements. This is a common challenge for manufacturers of technical solutions, particularly in software development, which adds cost and risk to projects [5]. These added costs can be minimised by user-centric innovation, which ensures the solution is based on an in-depth understanding of the domain as well as the problem to be solved.

3 TECHNOLOGY TRENDS

A number of high-level trends are continuously improving the ability of users to develop their own innovations, and these shall now be discussed.

3.1 Embedded devices

Recent development of small, affordable computers with sufficient processing power and functionality to make them useful has empowered people to have a go at making rather than consuming technology. This trend, known as the *Maker Movement*, has led to the creation of a myriad of innovative products incorporating embedded computing [6].

Many of the suppliers of embedded devices release the schematics under open source licences. Some of these require derivatives to be released under a similar license; however, there are options, such as MangOH [7], which permit derivative products to be released commercially. This opens up significant possibilities to industry.

2005 saw the release of the Arduino [8]; a small prototyping board consisting of an ATmega128 microcontroller, an integrated development environment based on *Processing*; a language for non-programmers, and library functions to easily program the microcontroller. This was an open source product but required derivative products to be licenced with the same permissions, which has generated a thriving community and culture of both technical and non-technical innovators.
Since then, devices incorporating microprocessors capable of running a Linux-based operating system have offered even greater possibilities. The *Raspberry Pi* is a credit card sized device first introduced in 2012 and now on its 3rd iteration which boasts a 1.2 GHz 64-bit quad-core processor

and built in Wi-Fi at a price tag of just £25. Since its introduction, over 8 million units of the Pi have been sold as well as similar offerings from other suppliers [9]. The evolution continues, with products now in development that are ten times faster than the current Pi, such as the *UDOO* [10].

3.2 Connectivity

A trend that has very much influenced our way of life is the increase in the number and variety of devices connected to the Internet. Mobile devices now take many forms, with *4G Long-Term Evolution* now a globally adopted standard, facilitating the use of *Internet Protocol* (IP) services completely wirelessly. This makes it easier than ever for us to be connected 24 hours a day.

Machine-to-machine communication, now referred to as the *Internet of Things*, is becoming increasingly prevalent, largely due to cost effective embedded systems, improved data transmission via a variety of protocols and the ability to process and extract value from data sets previously too large to manage – known as *Big Data*.

With most mobile devices now comprising fast processors and IP connectivity, deployment of applications is as straightforward as sending a link to anyone with a compatible device. Hosting and authentication can be handled via an abstract layer provided by cloud services.

3.3 Cloud computing

The delivery of on-demand computing resources over the Internet on a pay-for-use basis has now evolved to the stage where it is considered a viable and secure option, with many major corporations and banks now relying on the cloud for mission-critical applications [11].

A number of models have become popular: *Software as a Service* (Saas) gives access to innovative applications and scalable computing power, while *Platform as a Service* (PaaS) models provide the environment in which applications can be built and delivered without the need to provision and maintain hardware or software licences. *Infrastructure as a Service* (IaaS) makes servers, data storage and networking possible with no need to provision or maintain physical equipment. With security features, automatic scaling and flexible pricing structures, cloud computing can offer significant value with minimal investment.

3.4 Web technologies

The evolution of the Internet has transformed our interactions with each other and our access to information. The term *Web 2.0* was coined in 1999 by Darcy DiNucci [12] and popularised in 2007 by Tim O'Reilly [13] to represent the shift towards a new paradigm of openness and democratisation for the web. This encompasses social media, applications that run in browsers and closer integration of data [14].

Originally used solely by scientists and governments in the 1980s, the Internet has come a long way to the interactive dynamic web we know today. *HTML5*, the current specification, was finalised and published on 28 Oct 2014 by *The Worldwide Web Consortium* (W3C), with close collaboration between browser vendors ensuring maximum compatibility of features. *JavaScript* (JS), originally developed by Netscape in 1995 to make websites more dynamic, has also evolved significantly and the 7th version of the defining standard, *ECMAScript-262,* was finalised in June 2016. Many frameworks and libraries, almost all open source, have been built on top of the language, opening up vast possibilities for developers. Facebook's *React* and Google's *Angular.js* are just two of many open source JS frameworks for building dynamic web applications, and a vibrant community of developers is continuously creating libraries and tools for accomplishing various tasks from maths functions to interactive visualisations, providing significant flexibility.

With mobile devices now capable of running advanced web applications, a trend towards responsive web design enables applications to adjust according to the device on which they are run to behave like native applications.

3.5 Democratisation

It can be clearly seen from the examples discussed that technology is having a democratising effect. The fact that the average person carries a device in their pocket that would outperform early supercomputers supports this statement. This move towards democratisation is having an impact on business. Wolf [14] defines four pillars of democratised business, all of which are enhanced by technology:

Democratised knowledge

Access to information on a wide range of subjects is available via the Internet and is ever growing. *Massive Open Online Courses* (MOOCs), many of which are free and provided by respected institutions are increasing in number, providing a wealth of knowledge. Specific questions can often be answered by peers through online forums, if they have not already been answered and made available online. Individuals and organisations regularly upload tutorials and how-to videos. *Creative Commons* licencing makes it possible to release open source material with clearly defined permissions from the creator, facilitating the sharing of information.

Democratised creation

An open source approach to software enables large scale collaboration and feedback as well as democratised tools for creativity. As well as the examples previously discussed, open source software packages such as Computer Aided Design (CAD) software make advanced product design tools accessible to all, and low cost 3D printers have also democratised the production process.

Democratisation of funding

Not only is the initial outlay to launch an advanced technical product vastly reduced thanks to the democratised creation process, but there is the ability to efficiently scale up funding acquisition through the process of crowd-funding, where a product has potential value for a large number of users.

Successful projects, such as the *+POOL* project to build a filtered floating swimming pool in New York, and *GoldieBlox*, a construction toy and book series to promote engineering amongst young females, each raised over a quarter of a million dollars through crowdfunding and brought their ideas to fruition. These are just two of many such examples.

Democratisation of distribution and commerce

Distribution of software is now easier than ever via the web or through app stores. E-commerce enables direct payment from mobile devices, providing instant access to a global market.

The combination of the above factors results in the ability for firms or individuals to create products that effectively satisfy a requirement with minimal investment. In the commercial world there are many examples of small business that have developed *disruptive* technology which has taken over existing markets, often despite the competitors being large corporations with excellent management processes [15]. Businesses such as *Uber* and *Air BnB* have successfully used technology to open up new markets and rapidly scaled up and built on their initial success to capture long established ones.

4 APPLICATIONS IN LIFT & ESCALATOR MAINTENANCE

Over the past two years, the author has attempted to take advantage of the technology trends previously described to improve the capability of London Underground's Jubilee, Northern & Piccadilly line (JNP) maintenance organisation to make effective decisions to optimise safety, reliability and cost. The following examples, although within the domain of lift and escalator maintenance, demonstrate the value of user-centric innovation based on an understanding of a specific need and the context in which a solution to this need must fit.

Two solutions shall be presented, both of which involve the management of data; an area which was identified as having potential for improvement. The first is a mobile solution to provide vital escalator asset data to staff at remote locations and the second is a web-based application which aggregates data from multiple sources for desktop, smartphone and tablet.

4.1 Mobile Escalator Asset Register

Asset component data for escalators, such as part numbers, drawing numbers and configurations, are held in a database which is managed by an in-house design team. The database is used to inform maintenance activities and asset management, and has the ability to generate updates to a Computerised Maintenance Management System (CMMS) which holds a subset of the data. This presented two areas for improvement. Firstly, the full database was only accessible via a PC on the company network, limiting access at remote sites or in meetings. In some cases this caused delays in carrying out site work. The other area for improvement was in the process by which the data was kept up to date. The existing process to add corrections to the database involved ad-hoc chains of communication which were unreliable.

All maintenance team leaders are issued with iPhones and iPads so it was decided to utilise these to make the full database available remotely. To enable a solution to be developed, a software package called *Filemaker* was used. Filemaker, owned by Apple, is marketed as "Powerful, easy-to-use software used to create custom solutions that run on iPad, iPhone, Windows, Mac, and the web". This software was chosen as the use case was achievable with the built in features, including mobile support, security and authentication. The solution retained the original database as the master but enabled it to be uploaded periodically to a cloud server which could then be synced to mobile devices. The solution was designed such that data could be located via an easy to use interface, and developed through close collaboration and regular feedback from other end users of the application. The data is stored locally on each device, with no signal is required to view it, and it can be synced with the master database when signal is available. Staff can submit data corrections via the app itself, which go directly to the design team who can update the master database. The app has now been deployed within the JNP maintenance organisation and is regularly used for emergency and planned maintenance and asset management activities.

The initial investment for software licences was approximately £2,400, which included the ability to host the master database on a server with up to 10 concurrent user connections (only required for the syncing process) and the option of increasing this at a later date. The mobile version of the software was free to download from the App Store by individual users, who could access the app via an authentication process. A cloud server was set up with *Amazon Web Services* at a cost of approximately £20 per month, although for the first 12 months there was no cost due to the use of the introductory *free tier* offered by Amazon to new customers. The design of the system was intuitive and self-explanatory, and no training was required for the users.

The author's experience in setting up and learning the software was positive, with a variety of learning materials provided by Filemaker. The debugging functionality provided by Filemaker was found to be invaluable during the development process.

Although the gentle learning curve make this an effective option for managing data and presenting it via custom interfaces, the limited options for data visualisation and difficulty in connecting to non-standard data sources mean it is less effective for complex applications. Scalability is also limited, so the platform would not be suitable for an enterprise-wide solution to be rolled out across London Underground. It has, however, enabled a low cost solution to be designed and implemented which solves a real problem, adding value to maintenance. Should the business decide to implement an enterprise-scale version, this provides a successfully tested prototype, reducing the amount of development work that would be required.

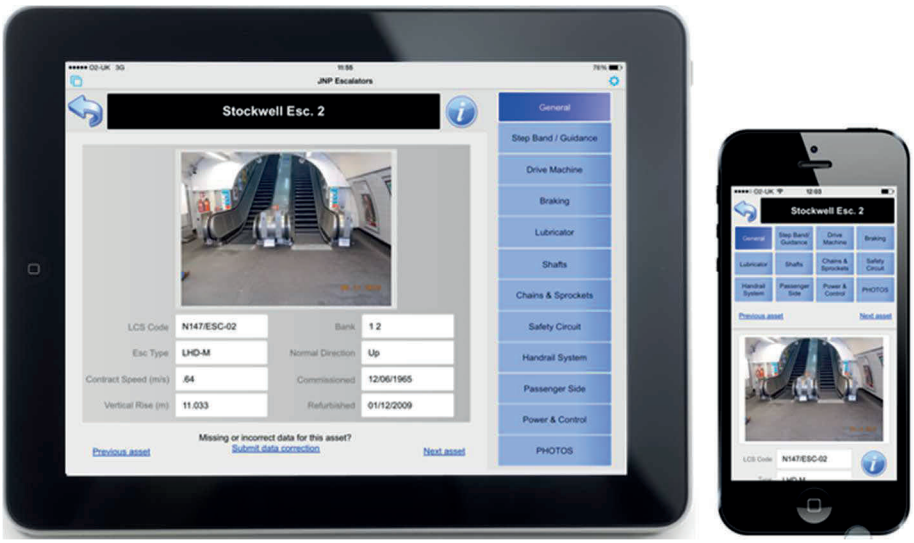

Figure 1: Mobile Escalator Asset Register

4.2 Managing multiple data sources

As part of London Underground's condition-based approach to maintenance of lifts and escalators, data from various sources are captured and analysed to gain a better understanding of the condition of the assets and identify potential failure modes. The following data sources are used:

- Remote temperature and vibration monitoring systems
- Offline vibration monitoring with a handheld device
- Thermography of electrical and mechanical components
- Gearbox oil analysis
- Ultrasonic monitoring
- Visual inspections and site reports
- Asset component data
- Work order and failure history
- Photos, videos, audio, drawings and station layout diagrams

Some of the above require specialist proprietary software for importing and processing data, and other data comes from databases hosted by third parties and emailed files. It was found from experience that accessing separate systems and databases to obtain the full picture of the assets was time consuming and detracted attention away from the analysis process. The aim of the solution was to provide a high level overview of all relevant data via a single user-friendly interface, enabling the users of the system to focus their attention on value-adding tasks.

Due to the complexity required it was decided to take the approach of developing a custom web application. This would make it possible to build a scalable and modular solution that would work on any device with a modern web browser, with scope to incorporate more assets and data sources

as well as analytics and visualisations at a later date. The JS framework *Angular.js* was selected due to its flexibility and open source licencing. An active community of users and the fact that it was backed by Google showed that it was well supported. Using open web technologies meant that there was zero investment required in new software or tools, the only cost being development time and the cost of cloud hosting. However, knowledge of web development as well as the frameworks used required more in-depth learning. The vast amount of information available online facilitated the learning process, but to keep up to date with web technologies is an on-going task. An alternative approach would be to invest in the support of one or more web developers.

After identifying the required data sources, it was necessary to make the data available in a consistent and web-friendly format. The format that was chosen where possible was *Javascript Object Notation* (JSON) which is both computer-readable and human-readable and popular with web applications. Initially, each data source was converted manually to enable the interface to be designed and demonstrated. The next stage, which is now in progress, is automating the extraction of the data from each system, format conversion and storage, ensuring up to date information is presented to the user.

Figure 2 shows a screenshot of the interface on a desktop web browser.

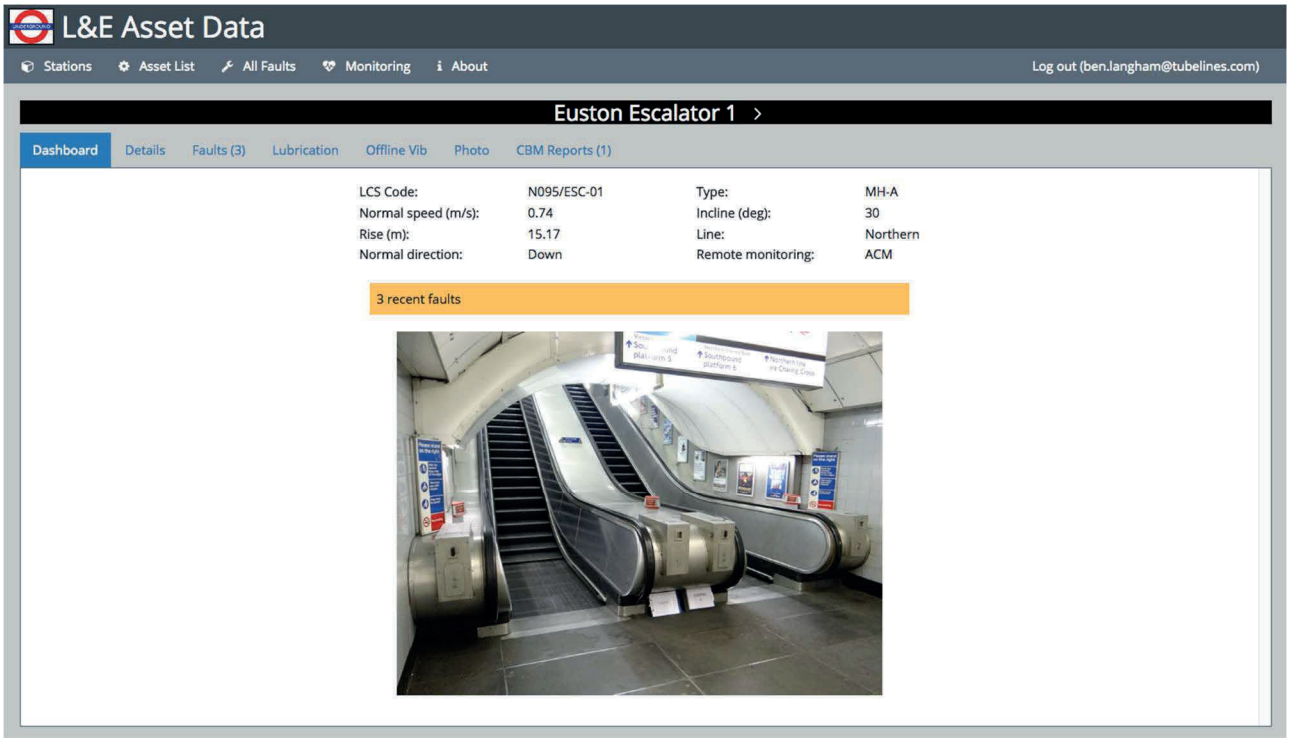

Figure 2: Web front end for access to multiple data sources

Other potential users of this solution include site fitters, maintenance and asset managers as well as senior management, who would benefit from an overview of the assets. End users were consulted and observed as part of an iterative design process whereby feedback was incorporated to ensure the design satisfied the user requirements as closely as possible.

Although the development of the system requires further work, it is already being used successfully to support group discussions such as failure review meetings, where it is displayed on a large screen and referred to when needed. It is also useful in the event of a fault to provide instant visibility of the history of the asset, known issues and monitoring data to aid the fault finding process. The ease of access to data also facilitates informed decisions relating to the frequency and extent of planned maintenance activities to be carried out. With maintenance driven by this data, smarter decisions

can be made when planning and scoping work, focusing resources and investment where they are most needed.

5 DISCUSSION

With customer expectations increasing and pressure on the business to improve efficiencies, there is certainly a drive towards more innovation in London Underground. The available technology is developing at a faster rate than that at which it is utilised and embedded in the business so there is significant potential to take advantage of the trends presented in this paper. London Underground is currently developing an innovation strategy to co-ordinate Research & Development projects, which is promising for staff within the business wishing to innovate and develop new technical solutions. In the wider industry, it is in the interest of businesses to have processes in place to support small-scale user-driven innovation, with many having successfully embraced this approach in the form of sponsored incubation programs. Without this, many ideas with potential value will not have the opportunity to be taken forward. This also provides visibility of technology across the business to ensure compatibility, avoidance of duplication and shared benefits as well as the ability to make commercial and strategic decisions regarding the organisation's technology assets.

Although the increased accessibility of technology can have significant benefits, the adoption of new technology should be done with consideration of the limitations and risks involved. One major risk when working with data is security, with accessibility of public cloud services presenting a possibility for sensitive or confidential data to be made public. Although cloud providers can encrypt data, it is often up to the user of the service to specify the security settings and configure authentication as well as scheduling backups to avoid data loss. With the number of devices connected to the internet growing rapidly, the number of potential vulnerabilities is also increasing, so cyber-security is a vital consideration, particularly where a security breach could have severe consequences. Provision of guidance and support for small-scale development projects would ensure compliance with the necessary standards and protocols.

The introduction of new processes, tools and technologies requires change management, and this is a common challenge to innovation. In a research report by Reliabilityweb.com, Bentley Systems identified organisational culture to be the biggest single obstacle to improving asset performance, but stressed that the proper tools, training and leadership, incorporating data-driven process management, can make it possible [16].

6 THE FUTURE

Improvements in connectivity are already making it much easier to share data, so it is feasible that this will develop to the stage where all data that could be of use to businesses will be instantly accessible, either manually or programmatically by scripts running seamlessly in the background. A shared data approach requires a paradigm shift in the way in which organisations operate. Departments previously separate from each other require open data policies and a collaborative approach in order for the benefits to be realised. Transparency across departments and with external bodies where appropriate can allow organisations to harness collective knowledge and maximise the benefits. Deciding on what data to capture and how to process it to extract useful knowledge and insights is a key challenge that will influence how much value is gained from data in the future.

Collaboration with the developer community is already happening at Transport For London, who have organised a number of hackathons, where large previously unused datasets have been provided to teams who have generated innovative and original solutions in a single day workshop. This approach is expected to continue with more developers becoming involved and more datasets made

available, gaining useful knowledge and improving the experience for the travelling public in London.

Software solutions incorporating machine learning and artificial intelligence are becoming more effective, as are products that enable these services to be incorporated into other applications. These are made accessible due to the data storage and distributed processing afforded by the cloud, and it is expected that these solutions will mature to provide maintenance organisations with intelligent insights to support fault-finding and fault prediction. These tools have already proved themselves in the aerospace and manufacturing industries and are now being considered on London Underground lifts and escalators which present a more varied asset base with less standardisation of design types adding complexity to the modelling.

Improvements in mobile technology are making virtual and augmented reality accessible to all with minimal investment. This could also have applications in maintenance, for example in visualising the movement of equipment in confined spaces, overlaying vital information about assets to staff during maintenance activities and for training. Therefore, this is an area where user-driven innovation could have significant potential.

An increased expectation for customised solutions to specific problems means that suppliers are changing their design and development processes. The ability to release software on the cloud is resulting in much shorter and more agile development cycles, with user feedback informing the scope of the design. Many software products are supplied as micro-services with open protocols enabling the customer to incorporate components in a modular fashion to create solutions that meet their specific needs.

7 CONCLUSIONS

It is now possible not only for ideas to be generated by users of technology, but also for them to be seen through to completion or to working prototypes of solutions. The cost savings that can be achieved by this approach are clear, as well as the likelihood of an effective solution being found, due to the advantage of an in-depth understanding of the problem and the domain or context in which it should fit. Where the skills or resources are not available to develop a solution, collaboration across the organisation or with suppliers can be an effective alternative.

This paper has presented two examples demonstrating the value that has been gained from user-led innovation within lift and escalator maintenance at London Underground. These have required minimal investment and have each addressed specific problems effectively, adding value to the business.

As technology continues to evolve, the potential for innovation that is available to all of us will increase further, and this will present greater opportunities. For businesses to harness the ideas that may arise within their organisation, a policy which provides the necessary support, tools, and some freedom to experiment, will enable these ideas to be taken forward, whilst ensuring the necessary strategic and commercial overview and management of risk.

REFERENCES

[1] Intel, 2015, Moore's Law, [Online], Available at: http://www.intel.com/content/www/us/en/silicon-innovations/moores-law-technology.html

[2] Oxford English Dictionary, Innovate Definition, Available at: http://www.oxforddictionaries.com/definition/english/innovate#innovate__2

[3] von Hippel, E., 1988, The Sources of Innovation, Oxford University Press

[4] von Hippel, E., 2005, Democratizing Innovation, The MIT Press

[5] Box UK [Online], Available at: https://www.boxuk.com/insight/blog-posts/importance-domain-knowledge

[6] Techopedia, Maker Movement [Online], Available at: https://www.techopedia.com/definition/28408/maker-movement

[7] MangOH [Online], Available at: http://mangoh.io/

[8] Arduino [Online], Available at: https://www.arduino.cc/

[9] ELinux, History of Raspberry Pi, [Online], Available at: http://elinux.org/RPi_General_History

[10] Kickstarter, UDOO [Online], Available at: https://www.kickstarter.com/projects/udoo/udoo-x86-the-most-powerful-maker-board-ever

[11] IBM, Cloud Computing, [Online], Available at: https://www.ibm.com/cloud-computing/what-is-cloud-computing

[12] DiNucci, D, Fragmented Futures, [Online], Available at: darcyd.com/fragmented_future.pdf

[13] O'Reilly, Web 2.0, [Online], Available at: http://www.oreilly.com/pub/a/web2/archive/what-is-web-20.html

[14] Wolf [Online], Available at http://www.forbes.com/sites/michaelwolf/2012/11/05/the-new-era-of-democratized-business/#cb93106190e1

[15] Christensen, C. M., 2006, The Innovator's Dilemma, Collins

[16] Reliabilityweb.com, 2014, Research Report on Asset Management Practices, Investments and Challenges 2014-2019. www.reliabilityweb.com

BIOGRAPHICAL DETAILS

Ben Langham has a BEng in Mechanical Engineering from the University of Reading and an MSc in Advanced Engineering Design from Brunel University. He has worked in maintenance on the London Underground since 2006 when he joined the Metronet Rail engineering graduate scheme. For the past 8 years he has been based in lift and escalator maintenance at London Underground, first as a Performance Engineer and currently as a Condition-Based Maintenance Engineer.