Office for Product Safety & Standards

Safety of Smart Domestic Appliances

A review of the opportunities for smart technology to enhance product safety

March 2023

Acknowledgements

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- National Fire Chiefs Council
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- Which?
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Executive Summary

An estimated 0.75 million accidental injuries each year are caused by unsafe products. Appliances specifically are a leading cause of fires with incident data indicating that these made up almost half of all fires in dwellings and other buildings in England between 2010 and 2020.

In addition to preventing the entrance of unsafe products into the supply chain, product recalls are a method of getting unsafe products out of consumers' hands. However, the effectiveness of product recalls crucially depends on consumers receiving recall notifications, responding to them and either returning or disposing of products. Evidence suggests that return rates can be low with one reason for low participation being that consumers tend to have low awareness, exposure or engagement with recall messaging.

Considering the growing market for connected appliances, The Office of Product Safety Standards (OPSS) commissioned London Economics to carry out a study on the potential for connected technologies to improve safety in Large Domestic Appliances (LDAs). The specific focus of the study was on cookers, washing machines, tumble dryers, dishwashers, and fridge/freezers. The objectives of the study were to:

- Review the key themes and issues (detailed below);
- Understand the current and anticipated use of smart technologies to improve the safety of LDAs, including a review of uses of smart technologies in other sectors that could be transferrable to LDAs;
- Assess the drivers and barriers to implementation of smart technologies for the LDA industry; and
- Consider how other players in the ecosystem (standards-setters, regulators and manufacturers) could respond to the potential for safety-enhancing smart appliance development.

The study team used the following research tools:

- A literature review in the form of a Rapid Evidence Assessment;
- Stakeholder consultation with various experts representing consumer organisations, first responders, appliance manufacturers, and standards or regulatory bodies;
- A modelling exercise to estimate the potential value of implementing smart technology in domestic appliances.

Key study findings

Key areas of potential safety benefits from connected technology adoption

Condition monitoring and predictive maintenance

One major area of benefit is condition monitoring and predictive maintenance. Condition monitoring is the process of observing the condition of assets through the use of sensors to detect possible technical issues before it leads to significant damage[1]. The collection and advanced analysis of data can then be applied to predictive maintenance to predict which parts of a machine are likely to fail and when[2].

Condition monitoring, and the integration of smart technology into condition monitoring, is increasingly used in industrial settings, with condition monitoring experts noting that this technology is already used widely in industrial equipment and plant production. The key motivation for implementing condition monitoring in industry appears to be focussed more on functionality and reducing downtime rather than improving safety. However, the evidence does not suggest that condition monitoring has yet been implemented on a large scale in large domestic appliances (LDAs).

The literature and consultations with stakeholders have suggested there could be potential safety benefits including:

- Condition monitoring to detect potential failures relating to variables such as appliance vibration, temperature, pressure or moisture;
- Predictive maintenance to identify and flag faults to consumers or manufacturers before they develop into safety hazards;
- Improving the efficiency of repairs by helping to better identify the particular problem with the appliance and the parts that may be required to repair it; and
- Enhanced ability to identify the products that were the sources of safety incidents such as fires.

There are also functionality benefits for consumers, for example increasing the longevity of their appliance and accessing quicker and more efficient repairs.

However, there are also several challenges and limitations which could hinder the uptake of condition monitoring technology in LDAs. These limitations largely centre around the cost, practicality and effectiveness of installing sensors in an appliance to detect signs of early failures relative to other solutions. The uncertainty around how many sensors will be required for each appliance, how effective they will be to prevent failures and safety hazards, and the cost of installation may lead manufacturers to pursue other solutions to prevent safety hazards such as containment of components in fire-resistant casing. In addition, new risk factors may be introduced such as the storage and processing of the large amounts of data generated by connected technologies and condition monitoring.

Moreover, while lower costs and greater commoditisation of IoT components, chips and sensors may incentivise adoption, there may be a risk that these safety benefits are only implemented for more expensive, or 'premium' products.

Improving the effectiveness of product recalls

Product recalls are an important form of corrective action to remove unsafe or non-compliant products from consumers' hands. Evidence gathered during this study suggests that connected technologies can both reduce the need for a product recall and improve efficiency and safety during a recall, through channels including:

[1] Digiteum (2020) What is Condition Monitoring and How Does Internet of Things Improve It?
[2] RMS (2021) Importance of vibration analysis in maintenance.

- Remote repairs implemented through mechanisms such as software updates;
- Improved communication e.g. up-to-date information during a product recall, or conveying maintenance and safety information;
- Improved ability to 'track and trace' consumers who possess products that are impacted by a recall. Existing research and interviewed stakeholders indicated that IoT technologies can help manufacturers to more easily track and trace products and identify those with possible defects at any point in the supply chain[3][4]. Many stakeholders pointed out that sectors with more effective recalls (e.g. automotive) also have better traceability.
- Connected technologies may also enable remote disabling of unsafe appliances, which would prevent consumer exposure to the safety risk because of the fault in the appliance. However, stakeholders highlighted that there might be consumer protection issues if such remote disabling infringed on consumers' rights, or even lead to unintended adverse safety consequences e.g. disabling refrigerators used to store medication.

Other safety benefits

The research conducted for this study suggested there is scope for other potential safety benefits from connected technologies, including:

- Using consumer experience data to perform safety-enhancing software updates;
- Future design improved through data collected on appliance performance and usage;
- Communication with consumers to encourage appropriate usage;
- Greater longevity through early detection of faults or communicating with consumers about appropriate usage and maintenance of their appliance;
- Preventing accidents in the home and facilitative preventative care for consumers in situations of vulnerability

Drivers and barriers to adoption/implementation of smart technologies

The adoption or implementation of smart technologies to enhance safety in LDAs has a number of decision-making considerations, including:

- Consumer appetite for the safety aspects of smart LDAs: evidence suggests that selling-points for consumers tend to be in the areas of functionality, energy-efficiency, or convenience[5][6], rather than safety[7]. Indeed, many stakeholders pointed out that manufacturers may find it difficult to find a 'hook' to sell the safety benefits of smart

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[3] OECD (2019) Challenges to consumer policy in the digital age: Background report. In: G20 International Conference on Consumer Policy, Tokushima 5-6 September 2019. Paris: OECD Publishing, 1-53. Available from:
[4] OECD (2018), "Consumer product safety in the Internet of Things", OECD Digital Economy Papers, No. 267, OECD Publishing, Paris.
[5] Wilson, C., Hargreaves, T. & Hauxwell-Baldwin, R. (2014) Benefits and risks of smart home technologies, Energy Policy, Volume 103, Pages 72-83.
[6] Wang, X., McGill, T. & Klobas, J. (2018) I Want It Anyway: Consumer Perceptions of Smart Home Devices. Journal of Computer Information Systems 60(5) pp. 1-11
[7] BEIS (2020) Consumer attitudes to product safety Research report. BEIS Research Paper Number 2020/032.

LDAs to consumers. Moreover, stakeholders pointed out that even consumers who purchased smart LDAs frequently did not connect them.

- A range of standards and regulations protect the interests and safety of consumers of LDAs, and are key elements of the decision to adopt or implement smart LDAs. For example, one key challenge in the IoT industry is ensuring adequate regulation to protect consumer safety, without stifling innovation. A frequently expressed concern among stakeholders was that standards-setting and regulation needed to keep pace with technological innovation, which may be challenging. Moreover, some representatives of manufacturers pointed out that inter-regional differences in standards and regulations might place operators in more heavily regulated regions at a competitive disadvantage compared to others. In addition, several stakeholders highlighted the importance of a clear standardised definition of what constitutes ‘smart’ or ‘connected’ appliances.

- Moreover, cyber security and data privacy concerns can limit consumer demand for connected technologies[8]. A consumer organisation advised that greater connectivity also increases vulnerability to hacking and other cyber-security risks. However, several stakeholders pointed out that there should not be a significant barrier posed by data protection regulations and privacy concerns, so long as manufacturers are transparent regarding the data they collect and seek the appropriate permissions from consumers.

- Stakeholders highlighted a range of technological barriers that limit the adoption or implementation of connected technologies for LDAs. One key barrier is interoperability, or the ability for different systems to ‘talk’ to each other. A product safety expert suggested that connected technologies require systems to be integrated across product brands, otherwise the data collected may not be compatible and therefore its value will be limited. Stakeholders pointed out that another barrier to smart LDA adoption is the requirement for reliable fast WiFi connections, which in turn may lead to inequalities between regions or consumer groups; for example, older consumers[9].

- In general, manufacturer representatives indicated that the costs of integrating smart technologies into LDAs could be considerable, and included the costs of monitoring and processing the large volumes of data collected from such appliances. Such costs would be taken into account and integrating connected technologies into LDAs would typically be done when it was cost-effective to do so. Several stakeholders raised the concern that these costs may be passed on to consumers.

- The reliance on digital access and capability runs the risk of ‘leaving behind’ certain consumer groups[10]. Concerns about digital security and privacy may be amplified for consumers in circumstances that make them vulnerable and less able to advocate for themselves[11].

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[8] Sovacool, B. & Furszyfer Del Rio, D. (2020) Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. Renewable and Sustainable Energy Reviews, Volume 120

[9] Vaportzis, E., Clausen, M. & Gow, A. (2017) Older Adults Perceptions of Technology and Barriers to Interacting with Tablet Computers: A Focus Group Study. Front Psychol. 8(1687)

[10] Sovacool, B. & Furszyfer Del Rio, D. (2020) Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. Renewable and Sustainable Energy Reviews, Volume 120

[11] Scie (2019) [Safeguarding adults: sharing information](#).

Value of harm avoided through adoption and implementation of connected technologies in LDAs

The study modelled the impact of connected technology adoption on:

- The likelihood of fires starting; and
- The likelihood of severe harms arising from appliance fires

Parameters[12] road-tested with experts and stakeholders included:

- The likelihood of fires and severe harms arising from fires;
- Proportion of smart appliance ownership; and
- Proportion of smart appliances with condition monitoring capabilities;

The modelling exercise, which focussed on the safety benefits from condition monitoring and predictive maintenance, found that the value of harm avoided through connected technology adoption in the UK is relatively modest: between **1 and 17 fires** would be avoided per year (reduction of 0.05-0.8%), and **between £71,000 and £1.3 million** in avoided costs per year. This corroborates the qualitative findings from this study that the safety benefit of smart appliances is not particularly large relative to other benefits it could bring, such as improved functionality. This is because fatalities and severe injuries are generally low in faulty appliance fires, meaning it is unlikely that the small number of avoided fires modelled would reduce incidents of harm: around 1 in 153 electrical appliance fires involve a fatality and 1 in every 15 electrical appliance fires result in a hospitalised injury[13]. This was limited by estimates for the effectiveness and adoption of current condition monitoring technology alongside current trends in penetration and connection rates of connected appliances. A final, 'extreme' scenario where these challenges were overcome was also modelled, showing the potential for smart technologies to enhance safety of LDAs.

However, as pointed out by many stakeholders, human behaviour is also an important driver of the incidence and severity of fires. Therefore, while connected technologies can indeed help to reduce harms from fires, they cannot entirely eliminate fires.

Impact of smart technology adoption on uplift of recalls effectiveness

The study team also estimated the impact of adoption of connected technologies in LDAs on the effectiveness of product recalls through improved ability to track customers who might be impacted by a recall, and/or greater responsiveness to recall messaging.

The modelling conducted by the study team found that **connected technologies could result in up to 19,000 more recalled LDA units being returned per 100,000 products** (an increase of 19%). This highlights the potential positive impact connected technologies could have on consumer safety, particularly in terms of recalls. This figure assumes that slightly over two-fifths of appliances are connected, however, pushing the proportion of connected appliances further to 100% (considering the use of a mobile connection, for example) results in an increase of up to 66%.

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[12] Parameters were estimated and 'road-tested' separately for each appliance focussed on in the study.
[13] Home Office (2020) Detailed analysis of fires attended by fire and rescue services, England, April 2019 to March 2020.

Conclusions

The evidence collected during this study suggests that while connected technologies have the potential to bring a range of safety benefits to LDAs, there are a number of limitations and barriers to adoption to consider. Furthermore, while adoption of connected technologies can help to improve safety, the value of the harm avoided by connected technology adoption, in particular with condition monitoring, may be relatively modest considering current trends in adoption, connection rates and limited evidence on the effectiveness of condition monitoring in LDAs.

In contrast, modelling suggests that there is clear potential for connected technologies to positively impact the effectiveness of recalls and hence consumer safety. Additionally, if there is a greater widespread adoption of connected appliances incorporating condition monitoring, alongside a greater percentage of these appliances being connected, it is more likely that the safety benefits of smart appliances could be realised as seen in the ‘extreme’ example modelled.

1 Introduction

The Office for Product Safety Standards (OPSS) is a part of the Department for Business, Energy and Industrial Strategy (BEIS), and is the UK's national regulator for all consumer products except vehicles, medicines and food. Created in January 2018, it also leads UK government policy on product safety and market surveillance. In addition, OPSS is the enforcement authority for a range of standards-based regulations in the UK.

Maintaining and enforcing product safety is important in preventing various hazards and risks. An estimated 0.75 million accidental injuries each year are caused by unsafe products[14]. Appliances specifically are a leading cause of fires: for example, in England, the prevailing causes of fires in dwellings and other buildings are 'faulty appliances and leads', and 'misuse of equipment or appliances' constituting 46% of all fires between 2010 and 2020[15].

In addition to preventing the entrance of unsafe products into the supply chain, product recalls are a method of getting unsafe products out of consumers' hands. However, the effectiveness of product recalls crucially depends on consumers receiving recall notifications, responding to them and either returning or disposing of products. Evidence suggests that return rates can be low: in the neighbourhood of 10 – 20%[16]; however, publicly available data on recall effectiveness is limited and many stakeholders consulted as part of this study noted that this was likely an underestimate (see section 6.2.1). With one reason for low participation being that consumers tend to have low awareness, exposure or engagement with recall messaging[17].

1.1 The potential of smart technology for product safety

Smart appliances are devices with a form of connectivity to the Internet or another Internet enabled device (which could be frequently-used consumer electronics such as smartphones or tablets). This connectivity has the potential to enable users to control their appliance or enable manufacturers to track condition and maintenance status remotely. Throughout this report, for simplicity we use the term 'smart' to refer to a wide range of capabilities enabled through connectivity. Other terms that are often included within the bracket of *'smart'* are the Internet of Things (IoT) and Artificial Intelligence (AI)[18]. Implementing smart technology could provide several benefits.

Firstly, smart appliances could prevent harms arising from unsafe appliances, or unsafe use of appliances. For example, smart appliances allow users to ensure appliances are switched off – especially vital in the case of large domestic appliances (LDA) such as ovens which pose significant fire risks[19] if left on accidentally.

Secondly, IoT technology, such as sensors, could enable condition monitoring and predictive maintenance[20]. Recording and controlling specific physical parameters of LDAs will enable

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[14] RoSPA. (n.d.) Product safety key issues
[15] Home Office (2021) Fire statistics data tables
[16] Electrical Safety First. (2014). Consumer Voices on Product Recall. Electrical Safety First. Note that this figure may be an underestimate; many project stakeholders say that participation has improved.
[17] Consumers, Health, Agriculture and Food Executive Agency., & IPSOS. (2019). Survey on consumer behaviour and product recalls effectiveness: Final report. Publications Office.
[18] Dragani, R. (2020). Definition of Smart Appliances. Hunker.
[19] London Fire Brigade. (n.d.). Cooking—Fire safety at home.
[20] Digiteum. (2020). How IoT Improves Condition Monitoring Services. Digiteum.

manufacturers (and consumers) to observe and report faults – some of which are pre-indication of serious faults, which could cause fires and potentially other hazards. The incorporation of IoT into appliances could enable efficient predictive maintenance, condition monitoring and reduction of faults and safety risks - if manufacturers see commercial benefits they can feasibly exploit.

Thirdly, smart connectivity allows the appliance to notify the user if it needs to be repaired, or if there are any faults,[21] helping to ensure that malfunctions are identified, and products are recalled. This allows manufacturers to better inform their customers of product recalls and thus reduce the potential of harm caused by a fault in the appliance.

Other technologies such as AI are also beginning to be incorporated within smart appliances. Manufacturers such as Samsung have already begun to incorporate AI in LDAs with new washing machines which use AI to remember frequently used cleaning and drying cycles and suggest optimal settings[22]. If manufacturers continue to utilise AI, there is an opportunity for further improved condition monitoring and fault diagnosis for LDAs, especially when used in conjunction with IoT[23]. Examples and case studies of the potential and uses of smart technology are discussed in the report below.

1.2 Purpose and objectives of the study

This study examines the use and potential for smart technology to improve the safety of LDAs, with a specific focus on cookers, washing machines, tumble dryers, dishwashers, and fridge/freezers. The objectives of the study are to:

- Review the key themes and issues (detailed below);
- Understand the current and anticipated use of smart technologies to improve the safety of LDAs, including a review of uses of smart technologies in other sectors that could be transferrable to LDAs;
- Assess the drivers and barriers to implementation of smart technologies for the LDA industry; and
- Consider how other players in the ecosystem (standards-setters, regulators and manufacturers) could respond to the potential for safety-enhancing smart appliance development.

The research is expected to cover the following themes regarding the potential applications of smart technology:

- Better condition monitoring telling users about emerging safety issues before they become a serious problem;
- Safety-enhancing software updates;
- Getting unsafe products out of consumers' hands by alerting consumers about recalls/safety issues, or disconnecting/disabling devices or functions of appliances;

[21] Repair Aid. (n.d.). Everything You Need To Know About Smart Washing Machines. Repair Aid London Ltd.
[22] Ikoba, J. J. (2020). Samsung launches AI-powered Washing Machine and Dryer. Gizmochina.
[23] Ali, Y. H. (2018). Artificial Intelligence Application in Machine Condition Monitoring and Fault Diagnosis. Artificial Intelligence - Emerging Trends and Applications.

- Better data collection to enable analysis of product lifetime performance; and
- Other indirect safety-related benefits of smart appliances.

The report below will cover:

- The key safety benefits and opportunities of smart technologies;
- The barriers and drivers of adoption and implementation; and,
- A modelling exercise to estimate the potential value of implementing smart technology in domestic appliances.

The study team used the following research tools:

- A literature review in the form of a Rapid Evidence Assessment;
- Stakeholder consultation with various experts representing consumer organisations, first responders, appliance manufacturers, and standards or regulatory bodies;
- A modelling exercise to estimate the potential value of implementing smart technology in domestic appliances.

2 Key safety benefits of smart technologies

This section describes some of the key benefits and opportunities posed by smart technologies in:

- Predictive maintenance;
- Communicating/intervening with consumers; and
- Research and development.

We discuss these benefits in turns below.

2.1 Use of smart technologies in condition monitoring and predictive maintenance

2.1.1 Common safety issues or faults with domestic appliances

Large domestic appliances are a significant source of house fires. Cookers, dishwashers, tumble dryers, fridge/freezers and washing machines account for two thirds of domestic appliance fires in the UK[24].

Domestic appliances mainly give rise to fires either owing to faults in the appliances themselves or owing to improper use. Home Office research finds that the biggest cause of all domestic appliance fires in 2019/20 was the misuse of equipment or appliances, which accounted for 34% of all accidental fires, followed by faulty appliances and leads, which caused 15%[25]. This is largely driven by the fact that cookers are the most common source of LDA fires and the majority of these are caused by misuse of equipment or appliances (Table 2). Conversely, as can be seen in Table 2, the majority of fires with other LDAs result from faults in the appliance. According to analysis from Which?, faulty appliances (including LDAs and other smaller appliances such as kettles, vacuum cleaners and irons) result in an average of 3,103 fires per year in the UK[26].

Table 1: The number and cause of fires in LDAs (2019/20)

Appliance	Number of fires	Proportion of ALL LDA fires (%)	Proportion of fires in the appliance caused by misuse of equipment or appliances	Proportion of fires in the appliance caused by faulty appliances or leads
Cookers	8,001	81.9%	62.23%	2.51%

[24] OPSS (2022) Safety of Smart Domestic Appliances. BEIS research paper.
[25] Home Office (2020) Detailed analysis of fires attended by fire and rescue services, England, April 2019 to March 2020.
[26] In the two-year period between 1 April 2014 and 31 March 2016, there were 6,206 household fires caused by faulty appliances and leads occurring in the UK. Which? (2018) Revealed: the brands linked to the most appliance fires.

Washing machine	624	6.4%	1.28%	83.33%
Tumble dryer	668	6.8%	5.09%	68.71%
Washer/dryer	68	0.7%	2.94%	79.41%
Dishwasher	194	2.0%	0.00%	88.14%
Fridge/freezer	215	2.2%	0.47%	84.19%
Total	9,770	100.0%		

Source: Home Office (2020), England only, LDA fires include fires in cookers, washing machines, tumble dryers, washer/dryer combined, dishwashers and fridge/freezers.

Below we describe some of the common safety faults by appliance type and indicate the proportion of fires attributable to common faults.

Cookers

Cookers are the most common source of all appliance fires in homes. In 2019/20, cooking appliances were by far the biggest source of ignition, and these were responsible for 14% of fire-related fatalities in the same year[27]. Fires that originate in cookers are usually caused by human error rather than a technical fault, for example leaving food unattended while cooking, build-up of food deposits, or plastic packaging left on food cooking in the oven[28].

Washing machines, dishwashers, tumble dryers and fridge/freezers

There are several common safety faults that occur in washing machines, dishwashers, tumble dryers and fridge/freezers that were identified both in the literature[29] and by stakeholders. These include:

- Printed Circuit Board (PCB) failure
- Damage to the door switch which can lead to resistive heating of the contacts
- Motor start/run capacitor failure

Capacitor failures in particular were identified by a representative of LDA manufacturers as being very dangerous and could often fail with no warning at all. A representative of first responders identified door switches as a big issue with washing machines since there tends to be a heavy supply of electricity through the switch which can result in a fault. They also identified heating elements as a common issue in washing machines. For tumble dryers in particular, stakeholders frequently identified the risk of lint or fluff coming into contact with the heating element and catching fire. Dry lint and fluff was a primary cause of the 750 fires that originated from Whirlpool tumble dryers between 2004 and 2016[30].

[27] Home Office (2020) Detailed analysis of fires attended by fire and rescue services, England, April 2019 to March 2020.
[28] Ibid.
[29] Ibid.
[30] Which? (2018) Revealed: the brands linked to the most appliance fires.

Fridge/freezers account for a smaller number of fires but the evidence suggests that fridge/freezer fires are often serious when they do occur[31]. For example, a fridge/freezer was likely the source of ignition in the tragic event at Grenfell Tower in 2017. These appliances are generally left on at all times, therefore increasing the likelihood of a fire occurring or a fire going undiscovered for longer if it breaks out during times it is not being monitored e.g. during the night.

Other common safety issues that can potentially lead to safety hazards with large domestic appliances (fires, electric shock, and flooding) which were identified by stakeholders include:

- Poor connections
- Over-heating of components
- Broken conductors
- Failure of the insulation
- Arcing and sparking
- Leaks that tend to stem from bearing failures
- Appliances not being properly grounded when installed

A stakeholder representing first responders also noted that a key consideration with faults is the ability of the appliance to contain a fire. In the past, fridge/freezers were manufactured using highly flammable materials, such as the refrigerant or polyurethane foam insulation which could result in extensive damage in the event of a fire[32]. However, a revised standard has been published which requires the flammable plastic backs in fridge/freezers to be fire resistant.[33].

Data from the London Fire Brigade (LFB) provides information on the source of ignition in white goods fires between 2009 and 2020, excluding fires in cookers. Wiring insulation was the most common source of ignition across all appliances, except for tumble dryers. Some caveats to consider with this data is that these statistics do not distinguish between whether the fire was caused by misuse of the appliance or by a technical fault in the appliance. Furthermore, the dataset provides only the item in the appliance that was first to ignite, which may not necessarily be the cause of the fire.

Table 2: The proportion of appliance fires by sources of ignition in London

Appliance type	Capacitor	PCB	Wiring insulation	Internal fittings/part of structure	Raw materials	Other
Washing machine	1.5%	15.1%	36.9%	3.2%	29.2%	14.2%
Tumble dryer	2.1%	3.2%	24.2%	10.9%	16.3%	43.4%

[31] OPSS (2022) Safety of Smart Domestic Appliances. BEIS research paper.
[32] IFIC Forensics (2018) White goods and Fire Risks; Domestic Refrigerations.
[33] Which? (2019) New fire-risk fridge freezers uncovered.

Washer/dryer	0.9%	1.3%	34.3%	12.6%	29.1%	21.7%
Dishwasher	1.3%	4.6%	37.1%	15.6%	30.3%	11%
Fridge/freezer	6.2%	1.3%	35.6%	10.6%	29.6%	16.7%

Source: London Fire Brigade (2020) Fires in white goods from 2009

2.1.2 How could condition monitoring be used by LDA manufacturers to identify safety issues?

Several stakeholders pointed out that appliances are required to be safe under foreseeable use, and failures that result in a safety hazard such as an appliance fire are very rare. One manufacturer explained that to ensure safety, thorough risk assessments are conducted on every product, which is usually done using failure modes and effects analysis (FMEA). This tests everything that could fail, evaluating whether it is a potential safety risk and putting mitigation in place if required. They provided the example of noise filters in tumble dryers which could pose a safety risk if they failed, so to mitigate the issue they enclose it in a metal casing. Despite the view that appliances should 'fail safe', most stakeholders believed that there could be safety benefits to monitoring appliances while they were in the hands of the consumer using condition monitoring.

Condition monitoring is the process of observing the condition of assets through the use of sensors to detect possible technical issues before it leads to significant damage[34]. While traditional monitoring involves fixing machines when they break down or conducting scheduled maintenance, a more effective system requires the continuous recording of data on the machine's status[35]. Intelligence is then applied around the collected data to determine the condition of the machine or system[36]. Condition monitoring can provide significant time-saving and cost-saving benefits, as has been the case with condition monitoring in industrial equipment[37]. There is some potential that condition monitoring could also deliver these benefits in consumer items, as well as improving safety by monitoring a machine's fault before it fails completely or results into a safety hazard such as a fire[38]. Table 4 provides an illustrative list of condition monitoring technologies and the associated failures that can be detected.

Table 3: Condition monitoring measures and the possible failures condition monitoring can detect

What is monitored	Technology	Failures detected
Vibration	Vibration sensor	Imbalance, misalignment, looseness, and late stage bearing failure of a rotating asset in a machine. Gear defects, machine grounding, electrical issues, lubrication defects, cavitation, pump seal failure

[34] Digiteum (2020) What is Condition Monitoring and How Does Internet of Things Improve It?
[35] Falkner, H., Nelson, F., Parry, G., Almeida, A. & Fang, J. (2018) Application note: Electric motor performance testing and reliability assessment. ECI publication No.Cu193. Leonardo Energy
[36] Tuckwell, M. (2015) Condition monitoring: Why now? A Sagentia white paper.
[37] Akula, A., Goel, S. and Ghosh, R. (2017) Condition monitoring saves money and prevents failures, AIChE.
[38] Tuckwell, M. (2015) Condition monitoring: Why now? A Sagentia white paper.

Temperature	Temperature sensor	Over-heating components, ineffective cooling systems, capacitor deterioration[39]
Pressure	Pressure sensor	Blocked airways and filters
Moisture/Humidity	Moisture/Humidity sensor	Damaged seals, blocked airways, and filters
Flow	Flow sensor	Blocked or damaged pumps/drains
Electrical Properties	Motor Current Signature Analysis (MCSA), power signal analysis and voltage/current analysis	Broken rotor bars, bearing deterioration[40] electrical insulation deterioration[41], other component deterioration[42][43]

Sensor technology in condition monitoring

The key part of a condition monitoring system is the **use of sensors to measure key parameters of a machine** and using these measurements for diagnosing faults. Sensors can measure dynamic energy from vibration or flow, for example, as well as thermal energy and electric currents.

- Vibration analysis is a commonly used method for rotating assets in a machine. All rotating assets vibrate but an issue can be present when unique vibrations occur or the asset is vibrating more than usual. Different factors such as misalignment, imbalance, or looseness of an asset can be identified by sensors recording the magnitude of its vibration using the amplitude of vibration and the frequency[44].
- Motor Current Signature Analysis (MCSA) is considered a popular method for easily detecting faults. It senses electrical signals that are a direct by-product of unique fluxes in the vibrations of rotating assets and so can potentially detect failures more quickly than vibration analysis[45].
- Similarly, temperature sensors can detect temperature fluctuations in the machine's parameters and detect instances of overheating due to excess friction or where other mechanical issues have developed[46].

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[39] Hewitt, D., Green, J., Davidson, J., Foster, M., and Stone, D. (2016) Observation of electrolytic capacitor ageing behaviour for the purpose of prognostics. In: IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society
[40] Mehla and Dahiya (2007) Approach of Condition Monitoring of Induction Motor Using MCSA. Journal of Systems Applications, Engineering and Development, 1(1)
[41] Palem (2013) Condition-Based maintenance using sensor arrays and telematics. International Journal of Mobile Network Communications and Telematics, 3(3)
[42] Hewitt, D., Green, J., Davidson, J., Foster, M., and Stone, D. (2016) Observation of electrolytic capacitor ageing behaviour for the purpose of prognostics. In: IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society
[43] M.H. Mohamed Sathik, S. Prasanth, F. Sasongko, J. Pou (2018) Online condition monitoring of IGBT modules using voltage change rate identification, Microelectronics Reliability, 88-90.
[44] Prüftechnik (2017) An Engineer's Guide: Making Maintenance Matter, Document no. ALI 9.600.G, Edition 12
[45] Mehla and Dahiya (2007) Approach of Condition Monitoring of Induction Motor Using MCSA. Journal of Systems Applications, Engineering and Development, 1(1)
[46] Accelix (2018) Why you should take advantage of remote condition monitoring.

The second area of focus in condition monitoring is the **use of the data collected via sensors**. Data must first be transferred from the sensors to a monitoring station. In more advanced processes, this involves transmitting continuous streams of data wirelessly[47][48]. The data then needs to be aggregated and processed which involves understanding the normal operating conditions of the machine and individual parameters and identifying abnormalities. For example, this can include trend analysis whereby real-time data is collected over time and analysed for trends or features which indicate a failure has occurred. Once data has been collected and processed, information then needs to be communicated in a clear way either to the manufacturer or user so that corrective action can be taken in the event of a fault[49].

The collection and advanced analysis of data can then be applied to **predictive maintenance**. Reactive, or corrective, maintenance is also known as a "run until failure" approach, whereas the purpose of predictive maintenance is to predict which parts of a machine are likely to fail and when[50]. Technological advances may enable sensors which were typically used for reactive maintenance to be used for predictive maintenance. For example, the research indicates that vibration analysis typically allows for better reactive maintenance than predictive maintenance, as the detection of vibration of assets usually indicates there is already a fault[51]. However, more recently, the emergence of more advanced sensors and processing of data has made it possible to predict certain failures using vibration analysis up to 90 days in advance in industrial machinery[52]. By detecting the root cause of a fault using vibration analysis, it allows manufacturers to predict follow-on faults. For example, lubrication failure can be a root cause of failure in many rotating assets, and shaft deflection the root cause of pump seal failure. By monitoring these root causes it is possible to predict a failure to occur to the machine's assets (e.g. rotating assets and pump seals)[53].

Predictive maintenance can also involve applying predictive analytics over the past data collected. For example, using pattern recognition to decode the causal relationships between certain events and subsequent machine failures[54]. It could then be possible to determine how many runs of the machine it takes for a certain asset to show signs of failure, for example. Existing data could also be statistically analysed to develop a model for asset failures, and then compare real-time data against these models to identify anomalies[55]. So far in the literature there is no evidence regarding the accuracy of these predictive models for LDAs or how sensitive LDAs are to the quality of data they collect. However, where predictive models are routinely used in other industries, they could be used as potential indicators.

Condition monitoring in LDAs

Printed Circuit Board (PCB) failure is often caused by burnt components. This can be caused in the assembly stage of PCBs due to improper component spacing or incorrect installation, but this can also be caused by exposure to extreme heat in the machine[56]. Condition monitoring of the machine's temperature could therefore help to reduce exposure to over-

[47] Tuckwell, M. (2015) Condition monitoring: Why now? A Sagentia white paper.
[48] Palem (2013) Condition-Based maintenance using sensor arrays and telematics. International Journal of Mobile Network Communications and Telematics, 3(3)
[49] Tuckwell, M. (2015) Condition monitoring: Why now? A Sagentia white paper.
[50] RMS (2021) Importance of vibration analysis in maintenance.
[51] Ibid.
[52] IBM (2019) Why move from condition monitoring to predictive maintenance? – Part 1.
[53] Ibid.
[54] Palem (2013) Condition-Based maintenance using sensor arrays and telematics. International Journal of Mobile Network Communications and Telematics, 3(3)
[55] Ibid.
[56] Rayming Technology (PCB and Assembly) (2021) What Are the Common Factors That Cause PCB Circuit Board Failure?

heating. Another common cause of PCB failure is damage to soldered joints which often results from a broken component barrier leading to moisture or dust getting into the circuit board[57]. In this case, the monitoring of excess moisture, for example, could flag this before it leads to damage of the soldered joints.

Capacitors are major causes of failure in electrical appliances. Capacitor lifespans can be shortened by excessive current or heat as well as overuse of the capacitor[58]. While electrical current and heat both have the potential to be monitored using condition monitoring technology, one stakeholder pointed out that the monitoring of capacitor failure would be difficult given that they often fail due to the breakdown of their layers.

Compressors are critical elements of freezing and refrigeration; the compressor circulates refrigerant through the system. Vibration analysis technologies can be used to detect defects in the compressors by analysing parameters such as the imbalance or misalignment of rotating parts or worn sleeve bearings on the compressor[59]. A representative of LDA manufacturers also suggested that it could be possible to monitor the compressor in a fridge/freezer and from this data then evaluate whether it has been running longer than it should or flag an electric disturbance in an appliance and identify when products start to arc.

Several stakeholders were positive about the opportunity of flagging faults in large domestic appliances before they developed. One product safety expert suggested that the condition of the machine (e.g. vibrations, noise, and temperature) could be monitored internally in the machine or remotely by a separate system e.g. an app. A representative of a trade body suggested that since every component has a standard operating parameter, it can be flagged if it is recorded to be outside of that parameter.

Smart technology applications to condition monitoring

The availability of continuous and internet-enabled condition monitoring has been expanding rapidly with the Internet of Things (IoT) and the transition of manufacturers to Industry 4.0[60]. A main benefit of IoT capabilities to condition monitoring is the seamless integration between machine sensors, data transfer and storage, data analysis and finally communicating information to engineers or users[61]. Wi-Fi-enabled sensors can easily transfer data to a monitoring station where Cloud storage technology can enable the storage of large amounts of data[62]. Advances in smart devices and the platforms for data gathering is also generating an uptake in condition monitoring[63]. Smart technology can allow for push notifications to be set up to a smart device to alert the manufacturer of an issue[64], or to directly alert the user of the appliance. This can alert the user to carry out a required intervention such as switching off the machine, or informing them that maintenance needs to be carried out by an engineer.

[57] Ibid.
[58] Riello UPS (2020) Why do capacitors fail? White paper.
[59] Townsend (2019) Effectiveness of Condition Monitoring on Screw Compressors. International Journal of Engineering Inventions 8(3) pp. 41-51
[60] Falkner et al. (2018) Application Note: Electric motor performance testing and reliability assessment. ECI publication no, Cu193.
[61] Aheleroff, S., Xu, X., Lu, Y., Aristizabal, M., Velásquez, J., Joa, B. & Valencia,Y (2020) IoT-enabled smart appliances under industry 4.0: A case study, Advanced Engineering Informatics, 43.
[62] Tuckwell, M. (2015) Condition monitoring: Why now? A Sagentia white paper.
[63] Ibid.
[64] Accelix (2018) Why you should take advantage of remote condition monitoring.

Smart capabilities can go also beyond traditional predictive maintenance, for example monitoring a network of connected assets that interoperate with each other, as well as the possibility of automating maintenance tasks when issues are flagged via sensors[65].

Potential safety benefits

Some manufacturers are already incorporating connected technologies in LDAs to promote safety. For example, an interviewed manufacturer discussed their current range of connected products, including washing machines, tumble dryers and fridge/freezers which had many user benefits, including user safety. The products in question were connected through an app which the manufacturer believed provided easy control of appliances. The range of products also provided voice command, AI-powered personalised performance, energy efficiency, and proactive customer care[66]. The manufacturer pointed out that the product range had a proactive customer care feature, which provides 'Smart Diagnostics' of potential issues with the customer's appliances which can be communicated via Wi-Fi and appliance sounds. The appliances collect continuous usage data via sensors and any detections of abnormalities are relayed back to the user through a push notification on their app. These range from instances of misuse of the appliances, for example, too much detergent was used in the washing machine so the machine is running for longer than it should be, or issues with parts of the machine that could lead to malfunction. For instance, users receive a notification if the airflow is not running smoothly due to a duct being clogged or damaged.

A manufacturer mentioned that it is possible in their machines to monitor the water pressure through a pump, compressors, and the spin performance of machine to detect faults or things that could lead to fault if they are not dealt with. Another manufacturer suggested sensors could be placed to monitor the flow of water through a pump, where the slowing down of water could indicate a blockage or damage.

The stakeholders noted that this level of proactive customer care was reliant on the use of sensors. They also noted, however, that these benefits relied on customer's connecting their appliance to the app, which they may not be willing or able to do. This is one key challenge to consider as to what extent the safety benefits of smart condition monitoring can be realised depends on the actions of consumers, a common theme raised by stakeholders.

A further benefit of predictive maintenance which was mentioned, both in stakeholder consultations and in the literature, was increasing the efficiency of repairs[67]. A representative of a trade body pointed out that monitoring software may allow engineers to see exactly what the problem is with the machine and which parts will be required. They pointed out that an engineer can also arrange to fix a part that is developing a fault before it breaks down. This can benefit the user as this reduces time without a working machine in the house. Several stakeholders also mentioned the benefit of longevity in the appliance. By monitoring the conditions of the machine and taking corrective action where needed, it could prevent premature failure.

In addition to the technologies described above, which are implemented or considered by some manufacturers, existing research and stakeholder interviews suggested a number of further potential safety benefits of connected technologies using condition monitoring or predictive maintenance.

[65] GE Digital (2020) 5 Steps to Reaching Smart Predictive Maintenance.
[66] LG (2021) LG ThinQ.
[67] European Committee of Domestic Equipment Manufacturers (2018) Smart appliances for a circular society.

Condition monitoring utilising Internet of Things (IoT) capabilities could have important applications for the monitoring of common faults to prevent a safety hazard[68]. For example, internet-enabled temperature sensors in an appliance in the home could reduce the occurrence and harm of fires[69]. The sensors could detect overheating in the appliance, which remotely alerts engineers or users. For example, past research has considered the benefit of installing temperature sensors in cooker hoods or stove tops to reduce the likelihood of a fire[70]. The type of sensors considered in the research had the ability to automatically shut off the cooker in response to detecting a potential dangers, for example in response to the sounding of smoke alarm[71]. Smart cooker sensors currently exist on the market. The Safera Sense cooking sensor, for example, can be installed above a stove and monitors temperature, power consumption and human presence. An alarm can sound if the sensor detects a possible fire risk and can also automatically shut down the power supply to the stove. If the user is away from the stove, they can be notified through an app that danger has been detected. The early detection of faults in a domestic appliance and the efficient corrective action can reduce the likelihood of a safety hazard such as a fire breaking out, or at the very least reduce harm from the very early detection of a fire. Similarly for reducing the likelihood of other harms such as electric shocks and floods caused by the faulty appliances.

Once an issue is detected, a connected device could trigger a notification for a human-executed response i.e. a filter change or notifying the manufacturer that the machine requires a replacement of a part[72]. For more serious detected faults, the device could self-diagnose and issue an advanced notification to an engineer or manufacturer of a fault that poses a risk. The continual data sharing of the machine’s parameters can allow an alert to be sent to the manufacturer automatically when anomalies are detected before the fault develops and without human intervention. In the extreme, if the manufacturer felt the appliance was at risk in operation, they could shut it down[73]. Stakeholders often noted the Samsung Galaxy Note 7 as a key example of using connectivity to alert the user of an issue and ultimately disable the device. While Samsung was successful in recalling over 90% of their smartphones, stakeholders raised the argument that there could be consumer protection issues around interfering with a consumer’s product that could limit the manufacturer’s ability to completely disable the appliance remotely.

Stakeholders pointed out that using such smart capabilities in condition monitoring could mitigate the risk of product failure and consumer harm since users only know appliances are failing when the failure happens. The benefits to condition monitoring and predictive maintenance are therefore that it reduces the risk of unexpected or premature failures of machines. Predictive maintenance also helps to minimise the cost and impact of unnecessary maintenance interventions[74]. Most stakeholders agreed that the concept of condition monitoring and predictive maintenance to prevent faults developing into safety issues would be positive from a safety perspective. Several stakeholders noted that condition monitoring needs to be predictive, for example, monitoring that alerts the manufacturer that the machine is overheating ahead of time so that they can remotely shut off the appliance. However, it would need to be managed correctly and is not the all-encompassing solution to product safety.

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68 The Invicta Group. How the Internet of Things is Changing Fire Safety.
69 Ibid.
70 Gill, J (2017) Cooker Fire Mitigation Device Assessment for Cheshire Fire and Rescue Service.
71 The Invicta Group. How the Internet of Things is Changing Fire Safety.
72 Ibid.
73 Ibid.
74 Falkner, H., Nelson, F., Parry, G., Almeida, A. & Fang, J. (2018) Application note: Electric motor performance testing and reliability assessment. ECI publication No.Cu193. Leonardo Energy

One further hypothetical benefit is that in the situation where a hazard could not be prevented and a fire ignited, IoT sensors and remote monitoring can be used to detect the exact location of the fire, where it is spreading, and how quickly[75]. This information could potentially be transmitted directly to the fire crew to provide greater insight into the fire. One stakeholder also raised the point that condition monitoring will be beneficial to the more effective identification of products that were the cause of incidents such as fires. Such identification was flagged as a significant concern, both by stakeholders and existing evidence. For example, a survey of 16 Fire and Rescue Services in 2015 reported that the make and model of 26% of white goods could not be identified after fires that were confined in the appliance, this increased to 49% if the fire had spread beyond the room of origin[76]. Therefore, better data collection through smart technology could prove useful in improving the identification of appliances that were the source of fires.

Additionally, fire forensics may be able to use information from smart appliances to determine the root cause of a fire. Identifying the root cause of incidences can both be very important for future prevention and could also enable a centralised database on the root cause of fires that do occur.

Limitations to condition monitoring

There are several limitations and risk factors to condition monitoring, however. While the increased use of sensors provides improved fault diagnosis capability, the additional sensors, cables, and other parts are in themselves a new source of malfunction. Furthermore, the management of big data is considered a challenging task for condition monitoring[77]. As machines become more complex, the volume of machine operating data is growing. To this end, the utilisation of smart technology to store and process large volumes of data is a promising approach[78]. Manufacturers then need to find the balance between collecting and processing data and the costs to them of doing so[79].

Indeed, several stakeholders had some reservations about the feasibility or effectiveness of condition monitoring. A number of stakeholders noted that some product safety events tend to be instantaneous and thus are very hard to predict, therefore were sceptical about the ability to flag a fault with enough time to prevent it becoming a hazard. A representative of first responders provided an example of capacitors, which fail by the breakdown of layers of plastic and metal and so would be difficult to monitor. While some research finds that characteristics of failure can be predicted in capacitors before complete failure in simulated conditions[80], a manufacturer suggested that capacitor failure is typically spontaneous and this would also make it difficult to flag before it became a hazard. Some research suggests that installing sensors in cooker hoods or stove tops could be effective at detecting hazards and isolating the power to the hob[81], during stakeholder consultations, manufacturers were sceptical that these sensors would effectively alert the user of a cooker fire prior to the user finding it for themselves i.e. by smelling smoke or being alerted by their smoke alarm.

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[75] IFIC Forensics (2018) White goods and Fire Risks; Domestic Refrigerations.
[76] BEIS (2017) Working Group on Product Recalls and Safety Report
[77] Falkner, H., Nelson, F., Parry, G., Almeida, A. & Fang, J. (2018) Application note: Electric motor performance testing and reliability assessment. ECI publication No.Cu193. Leonardo Energy
[78] Cao, Q., Giustozzi, F., Zanni-Merk, C., Bertrand de Beuvron, F., Reich, C (2019) Smart Condition Monitoring for Industry 4.0 Manufacturing Processes: An Ontology-Based Approach. Cybernetics and Systems 50(2) pp. 82-96
[79] Fitch, J. (2019) How the IIoT Is Changing Condition Monitoring. Noria Corporation.
[80] Hewitt, D., Green, J., Davidson, J., Foster, M., and Stone, D. (2016) Observation of electrolytic capacitor ageing behaviour for the purpose of prognostics. In: IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society
[81] Gill, J. (2017) Cooker Fire Mitigation Device Assessment for Cheshire Fire and Rescue Service

One stakeholder raised a concern regarding where the sensors would be best placed. If a thermal sensor was monitoring heat in a contained area of the machine, this might limit the effectiveness. Sensors could also be placed in positions within the machine based on functionality aspects and not safety, therefore might not be of use for improving safety. Stakeholders also mentioned that in order to monitor the specific parameters of an appliance, it could require many sensors for one machine and this might be impractical. This also raised the question as to whether this would be cost-effective.

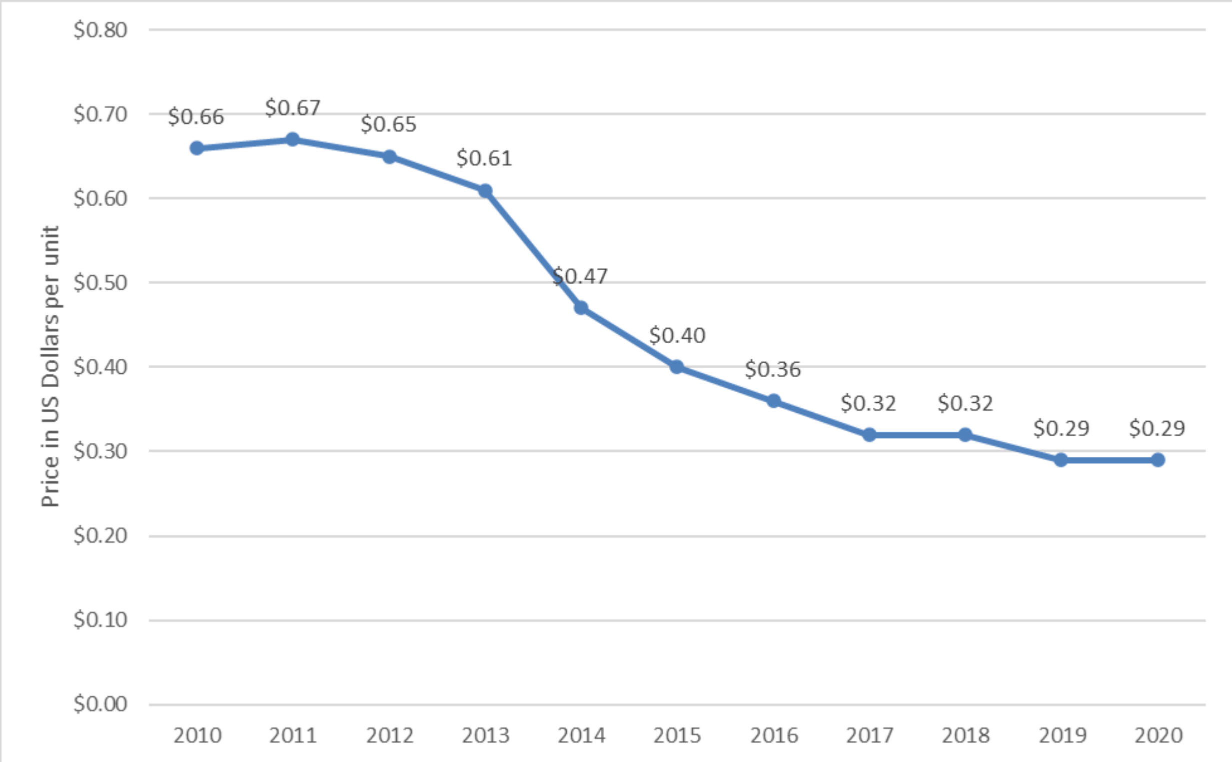
One representative of LDA manufacturers suggested that failure mode analysis could reduce the number of sensors required in one appliance. Failure mode analysis is the process of reviewing components and identifying the possible failures. This would enable manufacturers to identify the crucial points where sensors would be useful to preventing failure or a safety hazard and only place them in these points to increase cost-effectiveness. Several stakeholders suggested another more cost-effective solution might be to use failure mode analysis to find potential areas of the machine that were more at risk of causing a safety hazard and improving the design to prevent the hazard. For example, if there was risk of an item igniting, a more cost-effective solution could be to contain the item in a fire-resistant casing.

Another stakeholder noted that cost will be a prohibitive issue; firstly, the price of installing condition monitoring technology, and secondly the cost of continuously monitoring the data that the technology collects. Another stakeholder mentioned there would also be R&D costs involved to manufacturers researching this technology. Several stakeholders also raised the issue that the cost of condition monitoring would be passed on to consumers and questioned what this would do the price of these appliances. They suggested that if the installation of sensors in appliances significantly raised the price, then there is likely to be low consumer demand. However, they also noted that these technologies are more suitable for a large domestic appliance such as a fridge/freezer than small domestic appliances as large appliances already carry a higher price point. One stakeholder suggested that for a low-priced machine, the cost-benefit analysis might be negative, but for premium machines with longer warranties, there could be a real benefit of this to ensure the product does not fail before the warranty expires and to extend the lifetime of the appliance. One stakeholder also raised a concern for the market of repairs. Manufacturers conducting predictive maintenance could lead to monopoly market over repairs if the data collected cannot be shared with local repair shops. This may then tie consumers into more expensive repairs from the manufacturer.

On the other hand, there is some evidence to suggest that the falling costs of IoT components is a driving force behind IoT growth[82]. The commoditisation of components such as chips and sensors has been driven largely by the increased global demand for smartphone and tablets, which has driven down component costs[83]. Research by Goldman Sachs and BI Intelligence has found that the average cost of IoT sensors is falling[84], and its downward trend could mean an increase in the use of sensors for condition monitoring (Figure 1).

[82] OECD (2018), "Consumer policy and the smart home", OECD Digital Economy Papers, No. 268, OECD Publishing, Paris.
[83] OECD (2015), OECD Digital Economy Outlook 2015, OECD Publishing, Paris.
[84] Goldman Sachs (2014) The Internet of Things: Making sense of the next mega-trend.

Figure 1: Global average sensor sales price from 2010 to 2020 ($)



Note: Figures for 2016 to 2020 are forecasts
Source: Roland Berger (2017) Smart Strategies for Smart Sensors

Examples of smart condition monitoring in practice

Company	Condition monitoring technology	Aims
Verve	An energy monitoring device which connects to a mains supply or smart meter and uses algorithms to detect and analyse the unique wave signatures of different appliances. Using this as a baseline, an app could detect and inform the manufacturer or consumer of any deviations from the normal wave signature. The data can be used to determine energy use and cost, detect anomalies in equipment performance and identify faults before they occur[85].	The key aims are to reduce energy consumption and make white goods more efficient, longer lasting and sustainable[86].

[85] RIBA (2020) AI hones energy and carbon use profiles.
[86] Ibid.

Mitsubishi Electric[87]	Smart Condition Monitoring (SCM). Sensors detect normal vibrations of a machine and then identify patterns outside of normal operation which then alerts the maintenance team. The smart sensors have a learn function, which allows them to create a 'memory map' of the normal operating conditions, and sensors can be enabled using touch screen display, which also relays clear text information when an anomaly is detected.	The solution offers a predictive approach in plant maintenance. The SCM can detect failures such as bearing defects, imbalance, misalignment, and temperature measurement. The main aims are to ensure optimum asset performance and keeping downtime to a minimum.
Siemens[88].	Smart Condition Monitoring with Industrial Internet of Things (IIoT) sensors attached to mechanical assets in plants such as pumps, gearboxes and compressors. The multisensors measure vibration and temperature in assets and transmits this data via a Bluetooth connection to a Cloud gateway. The detection of anomalies is enabled by machine learning; parameters are constantly monitored and analysed to detect if there is any deviation from normal operating conditions. In the case of an anomaly, notifications are sent via SMS, email, or a mobile app.	The aim is to optimise plant performance by enabling potential incidents to be detected and prevented at an early stage, thus reducing maintenance costs and downtimes, and increasing plant performance by up to ten percent[89].

Exploratory research

In addition, Sankaranarayanan and Wan (2014) designed a prototype of an Android-based smart home monitoring system that uses wireless sensor network (WSN) to detect anomalies in electrical appliances remotely. They introduce a concept of developing a device that can detect electrical problems and present a solution to reduce the likelihood of ignition and a subsequent fire. Abnormal electrical condition can occur due to certain fault conditions such as an overloaded circuit or damaged insulation. This is considered to be an improvement to existing solutions, that is, a circuit breaker which trips once an electrical fault has occurred. It aims to prevent short circuits which can lead an outlet to start sparking and create an ignition source for a fire. The system uses sensors to monitor temperature, current and voltage periodically to determine anomalies in electrical distribution while using appliances that are plugged into sockets. If an anomaly is detected, the information gets transmitted to the user's Android mobile where they will be alerted of a potential fault so they can take action[90]. The

[87] Mitsubishi Electric Corporation (2021) Smart Condition Monitoring, A holistic approach to predictive maintenance.
[88] Siemens (2021) SITRANS SCM IQ Smart Condition Monitoring with IIoT Sensors.
[89] Siemens (2021) New Smart Condition Monitoring solution with IIoT sensors for industrial plants, Press Release.
[90] Sankaranarayanan, S. & Wan Au, T. (2013) ABASH — Android based smart home monitoring using wireless sensors. EEE Conference on Clean Energy and Technology (CEAT)

system architecture includes: the user of the electrical appliance; an Android device as the interface to receive alerts; a wireless sensor device installed in socket outlets; a server to store data; and wireless home network for connectivity. The aim of the system is to prevent a fire from occurring in electrical appliances and prevent loss of life, as well as to replace the need to check the wellbeing of wiring, sockets, and appliances physically by an electrician. It is worth noting that this design was a prototype and no evidence could be found of its development since this stage.

Summary

In summary, condition monitoring, and the integration of smart technology into condition monitoring, is increasingly used in industrial settings, with condition monitoring experts noting that this technology is already used widely in industrial equipment and plant production. The key motivation for implementing condition monitoring in industry appears to be focussed more on functionality and reducing downtime than for improving safety. However, the evidence does not suggest that condition monitoring has yet been implemented on a large scale in large domestic appliances (LDAs).

The literature and consultations with stakeholders have suggested there could be potential safety benefits including the early detection of appliance faults before they develop into a safety hazard such as a fire as well as the use of smart technology to communicate these faults to manufacturers and engineers. There are also functionality benefits for consumers, for example increasing the longevity of their appliance and accessing quicker and more efficient repairs.

However, there are also several challenges and limitations which could hinder the uptake of condition monitoring technology in LDAs. These limitations largely centre around the cost, practicality and effectiveness of installing sensors in an appliance to detect signs of early failures relative to other solutions. The uncertainty around how many sensors will be required for each appliance, how effective they will be to prevent failures and safety hazards, and the cost of installation may lead manufacturers to pursue other solutions to prevent safety hazards such as containment of components in fire-resistant casing.

2.2 Scope for smart technologies to improve the effectiveness of product recalls

Product recalls are a crucial part of consumer product safety and an important correction to prevent harm to users due to unsafe products[91]. The objective of a product recall for a business is to locate all unsafe products and either take corrective action to repair the product or remove them from the supply chain while effectively communicating with their customers about the risk and the required action[92].

Product recalls are frequently carried out for defective household goods. In some cases, recalled goods can present a danger such as a risk of fire. Global data from Allianz Global Corporate & Speciality based on analysis of 367 standalone product recall claims, the five most-frequently-recalled appliances are dishwashers (36%), washing machines (17%), fridge/freezers (8%), tumble dryers (6%) and cookers (3%)[93]. Data on average success rates

[91] OECD (2018[a]), "Measuring and maximising the impact of product recalls globally: OECD workshop report", OECD Science, Technology and Industry Policy Papers, No. 56, OECD Publishing, Paris.
[92] OECD (2018[b]) Working Party on Consumer Product Safety: Enhancing Product Recall Effectiveness Globally, OECD background report.
[93] Allianz (2021) Product recall - Preventing a crisis and the role of insurance. Expert Risk Articles.

for recalls is limited, but consultation with stakeholders alongside some evidence suggests that the average recall rate of electronic products was previously estimated to be low: in the region of 10-20%[94] . However, one stakeholder estimated the recall rate of white goods to now be higher at between 40% and 60%. Nevertheless, large numbers of faulty appliances could still be in consumer's homes and pose a significant safety risk[95].

Product recall data is still very limited, however. It is often **difficult for manufacturers or retailers to trace products held by consumers**, with only around 30% of people registering their products[96]. This figure was estimated to be higher for white goods, however, at around 53%[97]. One manufacturer pointed out that manufacturers tend to lose track of a product once it has left the retail floor. One way to identify consumers who hold a product is through product registration: by registering an appliance, manufacturers can gain access to the product's location and contact details of the user and can therefore easily contact the user in the event of a product recall[98]. However, manufacturers and interviewed product safety experts said that **relatively few consumers do register their appliances, and they believed there is significant scope for smart technology to improve this process**. For example, interviewed manufacturers said that consumers often needed to register their appliance to make use of the app or connected features, therefore connected appliances incentivise registration. One stakeholder even suggested that a connected appliance may eliminate the need to register the appliance and thus resolve the issue of low registration rates. With a connected appliance, manufacturers could also communicate a recall notice directly to users through their smart device, for example, via an app.

Whirlpool tumble dryer and washing machine safety campaigns

Tumble dryers

In 2015, Whirlpool issued a safety warning that millions of their tumble dryers were affected by a potential fire risk. An internal review following Whirlpool's purchase of Indesit revealed an issue in some of the models of tumble dryers where excess fluff could shift to the back of the machine over time and come into contact with the heating element, thus causing a fire[99].

In November 2015, Whirlpool issued a notice informing people of the risks with 5.3 million dryers across the UK sold between April 2004 and September 2015[100]. This covered models sold under Hotpoint, Indesit, Creda, Swan and Proline brand in 10 European countries including the UK, Croatia, Denmark and France[101]. The issue had resulted in at least 750 fires in the UK since 2004. Following intervention by the Office of Product Safety and Standards, in June 2019 Whirlpool announced a full recall of all remaining affected models that had not yet been modified. On the 13th of September 2019 Whirlpool published that 50% of the affected tumble dryers that were still in homes at the start of the campaign in 2015 had been resolved, which Whirlpool claimed was up to five times

[94] Electrical Safety First (2014) Consumer voices on product recall.
[95] Electrical Safety First (2014) Consumer voices on product recall.
[96]BEIS (2020) Consumer attitudes to product safety Research report. BEIS Research Paper Number 2020/032.
[97] Ibid.
[98] AMDEA (2021) Why register?
[99] OPSS (2019) Whirlpool Tumble Dryer Risk Statement
[100] Parliament.uk (2019) The safety of electrical goods in the UK: follow up.
[101] Which? (2021) Whirlpool tumble dryer safety alert, what are my rights?

the average success rate for a recall in the UK.[102] Although the overall recall rate was higher than average, there were a number of learnings for future recalls, these include:

* The importance of consumers registering ownership of their appliances to improve traceability.

* The importance of consistent and timely consumer messaging so that consumers understand what action to take and have confidence in the messaging[103].

Washing machine

Whirlpool also undertook a product recall of around 590,000 washing machines in 2019. Since the campaign was announced in December 2019, 271,186 customers had registered their appliance as part of the recall, which accounted for 45.9% of potentially affected customers. By March 2021, around 72% of the affected customers were identified as having an affected machine and had had their cases fully resolved by Whirlpool, 5% were identified as having an affected machine that at that time had not yet been resolved and the remaining were identified as not having an affected machine[104].

2.2.1 Benefits of smart technology on communication and product recalls

Connected technologies can bring a number of benefits related to increasing the effectiveness of product recalls, both through mitigating the need for a product recall and improving efficiency and safety during a recall. These benefits include the following areas, discussed in turn below:

- Remote repairs;
- Improved communication; and
- Track and trace.

Remote repairs

IoT can be used to remotely monitor the use of connected products and identify any defects before they become a significant risk to the user[105]. In cases where defects have been identified or reported, it may be possible that the manufacturer or supplier can initiate remote repairs such as software updates, thereby avoiding the need for the product to be recalled[106]. If the product cannot be repaired this way, it is also possible to use software updates to disable those products that have been recalled, preventing any further harm to customers once the recall has been initiated[107].

Consumers may be receptive to the use of IoT in a safety context: for example, in wave 2 of the OPSS Product Safety and Consumer survey[108], 50% of respondents said that they were at

[102] Whirlpool (2019) Whirlpool recall update: tumble dryer owners must come forward
[103] Peacky, K (2018) BBC News. The danger in our homes?
[104] OPSS (2021) Whirlpool washing machine recall update.
[105] European Commission (2020) Report from The Commission to the European Parliament, The Council and the European Economic and Social Committee Report on the safety and liability implications of Artificial Intelligence, the Internet of Things and robotics.
[106] OECD (2018) Working Party on Consumer Product Safety: Enhancing Product Recall Effectiveness Globally, OECD background report.
[107] Ibid.
[108] OPSS (2022) Product Safety and Consumers: Wave 2

least fairly comfortable with the use of remote software updates to prevent certain functions if there are physical safety issues. There have already been examples of product recalls where businesses have harnessed smart capabilities to achieve higher recall rates. For example:

- Samsung Galaxy Note 7s were recalled in 2016 due to some of the phones overheating and catching fire. Samsung used push notifications to alert consumers and implemented software updates to reduce the battery capacity of the smartphones to prevent harm[109].
- In 2016, a baby seat was recalled as it posed a fire hazard. The company used the Bluetooth app linked to the device to notify consumers of the recall and then disable the product[110].
- LG are currently recalling their Energy Solution battery due to instances of overheating and risk of catching fire. Similarly, they are implementing remote software updates to limit charging capacity to 90% to ensure safety before they can be replaced[111].

Improved communication

The IoT can provide unprecedented capabilities of facilitating direct and quick communication between product manufacturers, suppliers, and consumers. Often smart appliances can be linked to a user's smartphone or tablet via an app or software-based remote device[112]. This means that during a product recall, customers can be alerted directly to enable up-to-date information of the product recall status and what is required of them. This, therefore, presents a benefit for those users who had not previously registered their appliances. During the product recall of Samsung's Galaxy Note 7, multiple text alerts were sent daily to the users of the recalled smartphone to encourage them to switch off the device[113].

Improved communication may be particularly important for second-hand appliances. A study by Electrical Safety First (ESF) found in brick and mortar sales of second-hand appliances, the overall awareness of the need to check second-hand electrical goods against recall notices was low, particularly via private sellers[114]. Several stakeholders also referred to the effectiveness of product recalls in the second-hand market. One product safety expert estimated that around 30% of machines are with second-hand owners, so contacting these consumers was more difficult as these appliances are less likely to be registered. With embedded technology providing more up-to-date information, it would be potentially easier to contact these second-hand consumers directly.

More generally, several stakeholders highlighted that the ability to communicate directly with the consumer via email, text, or phone to share recall or other safety information would help improve the effectiveness of recalls. One representative of first responders suggested that there are currently huge gaps in the relaying of maintenance and safety information. For example, it would be beneficial if the appliance could give relevant maintenance messages such as 'change filter' or 'contact engineer'. However, several stakeholders also noted that, while being able to communicate with users is beneficial (e.g. keeping users informed of the status of their machine remotely if they chose to use it while they were away from the home), when it comes to a safety issue, the risk needs to be made absolutely clear and robust

[109] OECD (2019) Challenges to consumer policy in the digital age: Background report.
[110] OECD (2018) Measuring and maximizing the impact of product recalls globally.
[111] Energy Storage (2021) Overheating reports prompts LG Energy Solution battery recall.
[112] OECD (2018), "Consumer product safety in the Internet of Things", OECD Digital Economy Papers, No. 267, OECD Publishing, Paris.
[113] OECD (2018) Working Party on Consumer Product Safety: Enhancing Product Recall Effectiveness Globally, OECD background report.
[114] OPSS (2021) UK Product Safety Review: Call for evidence.

communication is essential. Clear communication of the issue to the consumer allows them to make an informed decision of whether to return their appliance, or instead choose to discard the appliance, stop using the appliance, or try to fix it for themselves. This improves the safety from recalled appliances even if consumers choose not to engage with the recall process. Data from wave 2 of the OPSS Product Safety and Consumer survey[115] finds that 15% of people threw away or stopped using their product when it was recalled[116] instead of returning, and 3% tried to fix it for themselves. One stakeholder raised the point, however, that communicating the message of a recall through a push notification to a smartphone, for example, means the manufacturer is limited to a smaller number of characters compared to a longer letter or email. They were concerned that the relaying of the message would not be as effective in a couple of sentences.

Track and trace

In the field of consumer product safety, traceability is one of the biggest issues[117]. With IoT technologies, manufacturers can more easily track and trace the whereabouts of a product and identify those with potential defects at any point in the supply chain[118][119]. Sectors with improved traceability frequently can have improved product recalls. Indeed, several stakeholders also mentioned the car industry as an area of application of smart technologies, specifically when it came to a 'joined-up' approach to traceability in the event of product recalls. The car industry was also pointed to as a sector where technology (including smart technology) is integrated to promote both safety and functioning of the product[120].

One manufacturer noted that losing visibility of a product once it has left the retailer is a problem for them, therefore, the ability to trace defective products, without relying on the user registering the appliance, is a significant benefit. Several stakeholders suggested that connected products would undoubtably impact recall effectiveness. A product safety expert suggested that with more granular data it will be possible to initiate a targeted product recall by identifying the exact batches of products that are affected and those users that have these products. One stakeholder suggested blockchain technology can be used to trace individual parts of a machine. In the event of a product recall, this would allow a manufacturer to easily see which batches have a defected part in them that came from a specific supplier, for example. This can allow businesses to increase the efficiency of the recall by contacting only those with the affected products[121]. For the manufacturer this could reduce the cost of the recall and be less burdensome on their reputation.

One stakeholder also noted that smart technology could allow the manufacturer to know when a product has gone out of service. This will be beneficial for product recalls as the manufacturer can track the recall success, as consumers may opt to throw away their product instead of responding to the manufacturer. In the aforementioned OPSS survey[122], 15% of

[115] OPSS (2022) Product Safety and Consumers: Wave 2
[116] A "product recall" being defined as a corrective action such as a repair or replacement – undertaken by a business to address safety risks in a consumer product and excluding any food, pharmaceutical, or vehicle product recalls)
[117] Wood (2016) UK consumer product recall: An independent review.
[118] OECD (2019) Challenges to consumer policy in the digital age: Background report. In: G20 International Conference on Consumer Policy, Tokushima 5-6 September 2019. Paris: OECD Publishing, 1-53.
[119] OECD (2018), "Consumer product safety in the Internet of Things", OECD Digital Economy Papers, No. 267, OECD Publishing, Paris.
[120] However, we note that the safety risks in relation to cars and other vehicles are different to the risks related to LDAs
[121] Renner, B., Fedder, C. & Upadhyaya, J. (2018) The adoption of disruptive technologies in the consumer products industry. Spotlight on Blockchain. Deloitte Insights.
[122] OPSS (2022) Product Safety and Consumers: Wave 2

people said that they either threw their product away or stopped using it in response to a product recall. This could be especially beneficial when there has been a large period of time between the product release and its recall and thus the product is more likely to be out of service.

Remote disabling of unsafe appliances

Many stakeholders referred to the Samsung Galaxy Note 7 recall as a good example of using smart capabilities to increase the effectiveness of the recall and ensure consumer safety in the process. One representative of first responders noted that the ability to disable or reduce the functionality of the appliance through a software update to prevent a safety hazard may be possible in LDAs. This would prevent consumers from using the appliance when it is unsafe to do so. Particularly since, as several stakeholders noted, people do not tend to register their appliance. The ability to remotely deactivate an appliance if consumers continue to use it despite being alerted of the risks, would ensure their safety during the product recall process. A couple of stakeholders highlighted that manufacturers should be careful, however, not to cross the line between control and safety, as some consumers might not be happy with being limited in this way. In an OPSS consumer survey[123], 32% of respondents said that they were uncomfortable with the use of remote software updates to prevent certain functions if there are physical safety issues. One product safety expert suggested that being able to forewarn consumers that their appliance will be turned off due to a safety risk strikes a good balance between protecting them and not leaving them in the lurch. Moreover, some stakeholders pointed out that disabling/deactivating LDAs might have unintended consequences which might have adverse safety implications themselves: for example, refrigerators might be used to store medication. Furthermore, manufacturers of LDAs may not see recall return rates as high as with the Samsung Galaxy Note 7 as smartphones are always connected because the internet is a key feature of the functionality of a smartphone. Whereas for an LDA, many consumers may not choose to connect their appliance, or may not realise it is unconnected.

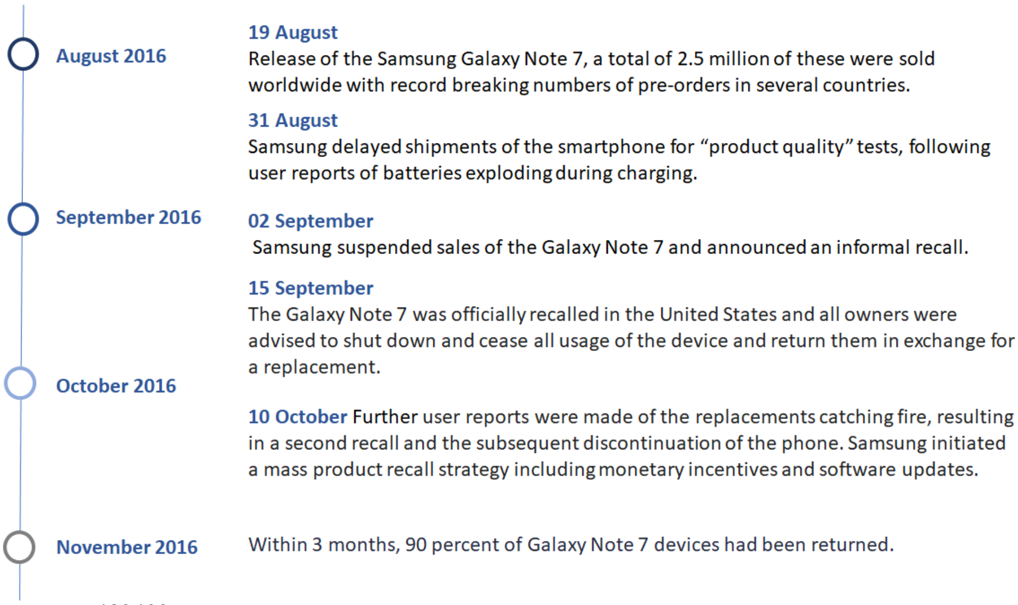
Samsung Galaxy Note 7 Recall

On 19th August 2016 Samsung Electronics released its Galaxy Note 7, a flagship smartphone described as their “best smartphone yet”. However, soon after its release, user reports were made of incidents where the phone had overheated and exploded. The crisis resulted in reputational damage to Samsung’s brand due to instances of serious human injury[124]. This was also the first mobile to be banned onboard an aircraft by the global transportation authority due to the combustion risk[125]. Samsung’s market value plummeted and operating profit fell by 30%[126]. Samsung carried out a successful product recall of the mobiles, taking advantage of the mobiles’ smart capabilities to increase the success rate of the recall and ensure consumer safety. Samsung Electronics America’s CEO called it one of the first digital recalls, using text message to communicate information of the recall to the smartphone users[127]. The recall was successful with 90%

[123] OPSS (2022) Product Safety and Consumers: Wave 2
[124] The Guardian (2016) Samsung Galaxy Note 7 recall expanded to 1.9m despite only 96 causing damage.
[125] Shamsi, A., Haider Ali, M. & Kazmi, S. (2017) Samsung Note 7 - An Unprecedented Recall That Created History: Exploding Phones Recovered – Exploded Trust? International Journal of Experimental Learning and Case Studies. 2(1) pp. 44-57
[126] Edwards, J. (2016) The first hard numbers on the Note 7 fiasco show 96% of Samsung's mobile profits wiped out. Business Insider.
[127] Forbes (2017) Samsung explains Note 7 battery explosions, and turns crisis into opportunity.

of the phones being returned within three months and a further 7% within seven months[128].

Figure 2 Timeline of the Samsung Galaxy Note 7 recall



Source:[129][130]

The Samsung Galaxy Note 7 recall is an example of utilising smart capabilities, or the Internet of Things (IoT) to increase the safety of smart devices, specifically in improving the efficiency of a product recall and enhancing the safety of consumers. Following its first official recall on 15th September 2016 Samsung issued a software update in South Korea that prevented the device being charged to more than 60% battery capacity in order to reduce the risk of overheating and subsequent combustion[131]. In December 2016, further software updates were initiated in other markets to disable the functionality of the device and prevent further harm to consumers. In Canada, Australia and New Zealand, a software update restricted the battery capacity of the device and also prevented the device from connecting to any wireless networks or use Bluetooth[132][133]. In the US, the software update prevented the device from being recharged at all in order to eliminate their use.

The connectivity of other devices also contributed to the effectiveness of the product recall. Facebook issued a software update to prevent the Gear VR virtual reality headset, which was an accessory sold alongside many of the Samsung Galaxy Note 7's as part of a promotional offer, from connecting to this particular device[134].

Samsung were also able to communicate effectively with their customers, which is essential for an effective product recall. Over the course of the recall they sent over 23

[128] OECD (2018) Measuring and maximising the impact of product recalls globally. OECD workshop report.
[129] Shamsi, A., Ali, M. & Kazmi, S. (2017) Samsung Note 7 - An Unprecedented Recall That Created History: Exploding Phones Recovered – Exploded Trust? International Journal of Experimental Learning & Case Studies, 2(1)
[130] BBC (2016) Galaxy Note 7: Timeline of Samsung's phone woes.
[131] Kim, Y. & McKinnon, J. (2016) Samsung Plans Software Update to Cut Galaxy Note 7 Fire Risk. Wall Street Journal.
[132] Reilly, C. (2016) Samsung works with Australian carriers to cut Note 7 network access.
[133] Goldman, J. (2016) Verizon Wireless agrees to brick Samsung Galaxy Note 7.
[134] Kastrenakes, J. (2016) Samsung confirms it will render the US Note 7 useless with next update.

million push notifications and alerts to its customers[135]. Samsung's successful product recall can largely be attributed to the use of its connectivity to ensure its effectiveness. It points to the use of such capabilities to improve the safety to consumers during a product recall and improve lines of communication through connected products[136].

Vodafone Safety Alert Message Indicator (SAMI)

Vodafone is the mobile world leader in Internet of Things (IoT) solutions, with over 100 million IoT connections in over 30 countries. Vodafone provides IoT solutions to businesses to suit their business needs, for example, improving operational efficiency, becoming more energy efficient or improve their consumer experience. Vodafone develops IoT-enabled hardware, such as IoT-enabled SIMs, and platforms to manage smart devices. Vodafone's Global Internet of Things (IoT) technology is the world's largest platform of its kind. In recent years they have since shifted their attention to home safety[137]. Vodafone is currently working with household and commercial appliance manufacturers on mobile controls and network technology[138].

In 2020, Vodafone's R&D team developed a smart product recall system that will allow manufacturers to send a notification to consumers in the case of a recall of a faulty appliance such as a washing machine, tumble dryer or a fridge-freezer[139]. The technology is a prototype system which uses an electronic device the size of a SIM card that is installed into an appliance. This provides a link to Vodafone's network which can be used to notify consumers of a recall or to remotely disable the machine in the case of a potential risk of harm to the consumer. The Safety Alert Message Indicator (SAMI) is an LED light on the product that is linked to the electronic device. It will show green if everything is as it should be, amber if the consumer needs to contact the manufacturer and red if there is a fault that needs attention immediately[140]. In a worst-case scenario, manufacturers would be able to remotely shut down the machine using Vodafone's network to reduce the risk of harm. This technology was also built to overcome the issue of non-registered appliances and second-hand markets as it will allow manufacturers to easily trace the location of appliances.

The Vodafone Safety Alert Message Indicator has received innovation awards from Electrical Safety First (ESF) and the Institution of Engineering and Technology (IET). They have also already received positive feedback from fire brigades and are now working with manufacturers to put this prototype into practice[141].

[135] OECD (2019) Challenges to consumer policy in the digital age: Background report. In: G20 International Conference on Consumer Policy, Tokushima 5-6 September 2019. Paris: OECD Publishing
[136] OECD (2018) Measuring and maximising the impact of product recalls globally. OECD workshop report.
[137] Vodafone (2020) Vodafone 'Smart' product recall system allows manufacturers to warn consumers of faulty goods. Press Release.
[138] Ibid.
[139] Ibid.
[140] Davies, J. (2020) Vodafone builds remote monitoring and product recall IoT platform. Vodafone UK News Centre.
[141] Vodafone (2020) Vodafone 'Smart' product recall system allows manufacturers to warn consumers of faulty goods. Press Release.

2.3 Other safety benefits of smart technologies

This section describes additional safety benefits of smart technologies, including:

- Software updates
- Better future designs
- Identifying products that may have caused incidents
- Additional benefits to connectivity

These benefits are discussed in turn below.

2.3.1 Other safety-enhancing software updates

Manufacturers can learn from the data they are collecting about the consumer experience of the device and any common issues that arise[142]. These problems in smart appliances can then be resolved through over the air software updates[143], for example, automatic software updates to fix bugs and patch security vulnerabilities[144]. Remote software updates can also be installed to run an appliance in "safe mode" while awaiting repair, for example, during a product recall[145].

2.3.2 Future design

In connected appliances, the ability of the manufacturer to monitor trends in the appliance's performance and the way it is used, means this information can be used to improve on the design of existing and future appliances[146]. Such monitoring is already used presently in personal computing, where data on crash reports is reported back to the software manufacturer.

One area that was noted by several stakeholders was the ability of manufacturers to use smart technology to monitor the usage patterns and performance of appliances and their components. One representative of manufacturers and retailers suggested this could help manufacturers to identify models that had common or increased failures. A number of stakeholders suggested that this data could be used to improve future designs of the appliance or advising consumers of how best to use the product. The benefits to the wider industry depend on how far manufacturers are willing to supply and share data on their appliances.

2.3.3 Communication with consumers to encourage appropriate usage

Several stakeholders noted that there is a difference between inherently unsafe products and products that become unsafe due to incorrect usage. Currently manufacturers are unable to tell how consumers are using their appliances, as consumer surveys are unlikely to be entirely accurate. Therefore, a smart appliance that is able to monitor and prevent incorrect usage would be beneficial. One consumer organisation suggests this risk could then be managed

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142 OECD (2018), "Consumer policy and the smart home", OECD Digital Economy Papers, No. 268, OECD Publishing, Paris.
143 European Committee of Domestic Equipment Manufacturers (2018) Smart appliances for a circular society.
144 OECD (2018) "Consumer policy and the smart home", OECD Digital Economy Papers, No. 268, OECD Publishing, Paris.
145 OPSS (2022) Safety of Smart Domestic Appliances. BEIS research paper.
146 European Committee of Domestic Equipment Manufacturers (2018) Smart appliances for a circular society.

through education of the user, risk mitigation or design modification. A product safety expert suggested that if there was good communication between the manufacturer and the user, manufacturers could establish a feedback mechanism whereby consumers are told how they can maintain and use their appliance better.

One representative of LDA manufacturers described two different systems that could be used. A passive system which involves interrogating usage logs and performance at the machine's end-of-life, for example by installing a memory chip into the machine in the manufacturing process. Or a live monitoring system that is permanently connected to provide usage data to manufacturers and could also alert consumers when they are using the machine incorrectly. The passive system is considered by the stakeholder as less intrusive.

Users may also be able to fix minor issues with the appliance on their own using video or phone guidance that is accessible through their smart machine or smartphone[147].

2.3.4 Additional benefits to connectivity

There has been substantial growth in the number of 'connected homes' and this is expected to continue[148]. Connected homes, or Smart Homes, are home setups where internet-based devices are integrated to automatically control attributes of the home such as lighting, entertainment, climate, security, and appliances[149]. There are potential safety benefits from this wider connectivity between several devices. For example, a connected fire alarm such as the Google Nest Protect[150].

Google Nest Protect

Google acquired Nest in 2014 which represented the second-largest deal in Google's history. This positioned Google as a key player in the market from smart home appliances in a time of growth for the Internet of Things (IoT)[151]. The Google Nest Protect is a smoke and carbon monoxide alarm which was first launched in April 2014 and the second generation in mid-2015[152]. The Nest product has several benefits:

- The Nest Protect can be connected to a smartphone using Wi-Fi through the Google Nest app.
- The device can send alerts or messages through the smartphone app in the case of a smoke or carbon monoxide warning, these can be received by any member of the household anywhere.
- Alerts are sent in the case of low battery of the device and it is possible to test the alarms through the app.
- In the event that smoke or carbon monoxide is detected, all of the alarms installed in the household speak and verbally identifies the location of the smoke or carbon monoxide detection.

[147] European Committee of Domestic Equipment Manufacturers (2018) Smart appliances for a circular society.
[148] McKinsey & Company (2016) Connected homes.
[149] Robes, R. & Kim, T. (2010) A Review on Security in Smart Home Development. International Journal of Advanced Science and Technology Vol. 15
[150] Oreskovic, A. (2014) Recall by Google's Nest reveals 440,000 fire alarms shipped in U.S. Reuters.
[151] Ibid.
[152] Mears, K. (2019) The Sibling Rivalry of Nest Protect: Gen 1 vs Gen 2. Smarthome.

- The alarm can also be linked to the Google Nest Learning thermostat to automatically shut off heating in the house, and the Google Nest Cam to trigger an emergency recording.

Shortly after the release of the first-generation Nest Protect, the US Consumer Product Safety Commission announced the recall of 440,000 of the alarms[153]. Nest discovered a defect in the device that could potentially delay a smoke or carbon monoxide alarm from sounding. This was linked to a Nest Wave that allowed users to temporarily silence alerts with a wave of the hand near the device[154].

To repair this, Nest halted its sales of the device and launched a product recall. The recall notice formalised the company's response to the defects which included a remote repair for the connected devices. Nest initiated an automatic electronic update that users could access from their smartphone or tablet which deactivated this specific feature. Once this was installed, the product could be used safely. Nest could also identify those alarms that could not be repaired remotely, for instance if they were not connected to a Wi-Fi network. The product recall also allowed the return of unconnected devices and for those consumers that opted for returning the device anyway[155].

Several stakeholders noted the wider benefits of connectivity with other smart devices. For example, a product safety expert noted the importance of the connected home as a key consideration in this study, as the benefits of an interconnected smart home could be more fruitful and could work more efficiently than standalone devices. Several stakeholders noted the potential of large domestic appliances to become part of the smart home ecosystem, and indeed, that is where it is heading. A manufacturer noted that their range of connected large domestic appliances includes washing machines, tumble dryers and refrigerators, and these white goods can talk to other smart products in the home. For example, a washing machine can display a message on a smart TV. However, most of the benefits stakeholders mentioned were functional rather than for safety e.g. the washing machine is connected to a smart speaker to inform the user of when the cycle has finished.

A number of stakeholders noted there was a potential benefit of connecting appliances to alarm systems. For example, a representative of first responders pointed out that consumers would benefit if any time an alarm is triggered this could be cascaded across other smart devices, which can give people more warning that helps them to exit their property quickly and safely. A consumer organisation pointed out that a similar capability could be an LDA linked to a smart speaker or a device that could contact emergency services in the event of an incident. Another example provided by a representative of manufacturers was the ability of a connected device to shut down the other appliances in the event of a fire to prevent adding to the fire risk.

2.3.5 Benefits relating to longevity

Other benefits of smart domestic appliances that were identified by stakeholders included increasing the longevity of the appliance. The use of smart technology in LDAs, for example through the early detection of faults, or informing consumers of the correct way to use and

[153] DiClerico, D. (2014) Nest Labs recalls Nest Protect Smoke + CO Alarm: A software glitch can result in a delayed fire alarm. Consumer Reports.
[154] Welch, C. (2014) Nest recalls 440,000 Nest Protect smoke detectors over safety risk. Consumer Product Safety Commission.
[155] OECD (2018) "Consumer policy and the smart home", OECD Digital Economy Papers, No. 268, OECD Publishing, Paris.

maintain the appliance, can prolong the life of the appliance. This could be an important driver of consumer demand for smart domestic appliances. In general, consumers tend not to consider safety when making purchasing decisions, and instead consider factors such as cost and quality more frequently[156]. Therefore, increasing longevity of the appliance could be a meaningful selling point to consumers.

One representative of manufacturers also noted that enhanced data collection through connectivity could help with the second-life of appliances. Manufacturers can better identify which products could potentially be refurbished by monitoring the internal conditions and interrogating the past usage data of the machine.

2.3.6 Safety benefits for vulnerable consumers

The research suggests that healthcare is a promising benefit area for smart technology in the home[157]. In a study by Sovacool and Furszyfer Del Rio (2020)[158], 31 experts were interviewed across different organisations. These included government departments (include the Department for Business, Energy, and Industrial Strategy (BEIS) and Ofgem), academic institutions, private companies (including Amazon and Microsoft), civil society and independent research institutions (including Citizens Advice) and intergovernmental organisations (include the European Commission and the International Energy Agency). Over a third cited that health benefits and assisted living was an important benefit of smart home technology. Chan et al. (2009) point out the significant potential for the use of smart technology to replace healthcare with home care, with the benefits being particularly acute for the ageing population and people with disabilities or chronic medical conditions[159].

Alaa et al. (2017)[160] review the literature on smart home applications based on the Internet of Things (IoT). They find a small number of studies that look into the use of Cloud or Android mobile apps in smart homes for managing various aspects of living for people with disabilities and the elderly[161]. For example, sensors, wearables, or implantable devices can facilitate preventative care and avoid incidents in the home[162]. There is also the potential for the use of smart technology to automatically alert relatives or the health services in the event of an emergency[163]. Companies are increasingly looking into using sensor technology in the home of a person suffering from dementia to monitor their habits and interactions with their appliances. This can allow carers to remotely monitor that the patient is remembering to drink by monitoring the number of times a kettle is boiled, or to check that appliances are used correctly, for example, to check the oven has not been left on. The Research Institute for Disabled Consumers (RiDC) carried out research into the benefits of smart connected products

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[156] BEIS (2020) Consumer attitudes to product safety Research report. BEIS Research Paper Number 2020/032.
[157] Gram-Hanssen, K. & Darby, SJ. (2018) Home is where the smart is'? Evaluating smart home research and approaches against the concept of home. Energy Res. Soc. Sci. 37 pp. 94–101
[158] Sovacool, B. & Furszyfer Del Rio, D. (2020) Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. Renewable and Sustainable Energy Reviews, 120
[159] Chan, M., Campo, E., Esteve, D. & Fourniols, J. (2009) Smart homes— current features and future perspectives. Maturitas 64 (2), pp. 90–97.
[160] Alaa, M., Zaidan, A., Zaidan, B., Talal, M. & Kiah, M. (2017) A review of smart home applications based on Internet of Things. Journal of Network and Computer Applications. 97 pp. 48-65
[161] Puustjärvi, J.& Puustjärvi, L. (2015) The role of smart data in smart home: health monitoring case. Procedia Comput. Sci. 69, pp. 143–151.;
[162] Wilson, C., Hargreaves, T. & Hauxwell-Baldwin, R. (2014) Smart homes and their users: a systematic analysis and key challenges. Pers Ubiquit Comput 19, pp. 463–476
[163] Sovacool, B. & Furszyfer Del Rio, D. (2020) Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. Renewable and Sustainable Energy Reviews, 120

in the home for disabled people[164]. Three members of a consumer panel tested the Amazon Echo, Apple Watch and Hive technology for two weeks.

- For a member with Multiple Sclerosis (MS), the hands-free nature of the Echo and Apple Watch enabled them to perform tasks such as switching appliances off. This was particularly beneficial as they suffered from balancing problems which sometimes resulted in a fall.

- For the members that were blind, the Hive also worked as a sensor which could alert them of objects in their path or the whereabouts of a pet, for example.

Several stakeholders also mentioned the safety benefits for vulnerable groups. Smart technology has the potential to help vulnerable users by making their life easier and safer in the home. One representative of manufacturers mentioned that people tend to care about the application of smart technologies to social care and devices that help vulnerable consumers. However, a stakeholder also noted that it is unlikely there will be substantial benefits unless the technology is bespoke for the vulnerable user, such that it is tailored to their specific needs. A consumer organisation pointed out that providing a smart appliance alone is unlikely to help them if it does not meet their requirements or they do not understand how to use it.

[164] RiDC (2017) Connect home technology. Our insights.

3 Drivers and barriers to adoption and implementation of smart technologies

While stakeholders tended to agree there were a number of potential areas of opportunity for connected technologies to improve safety in LDAs, their use in this context is not universal, and the decision to adopt connected technologies to enhance safety is not straightforward. This section discusses the current state-of-play of adoption of smart technologies, and the drivers and barriers to their implementation.

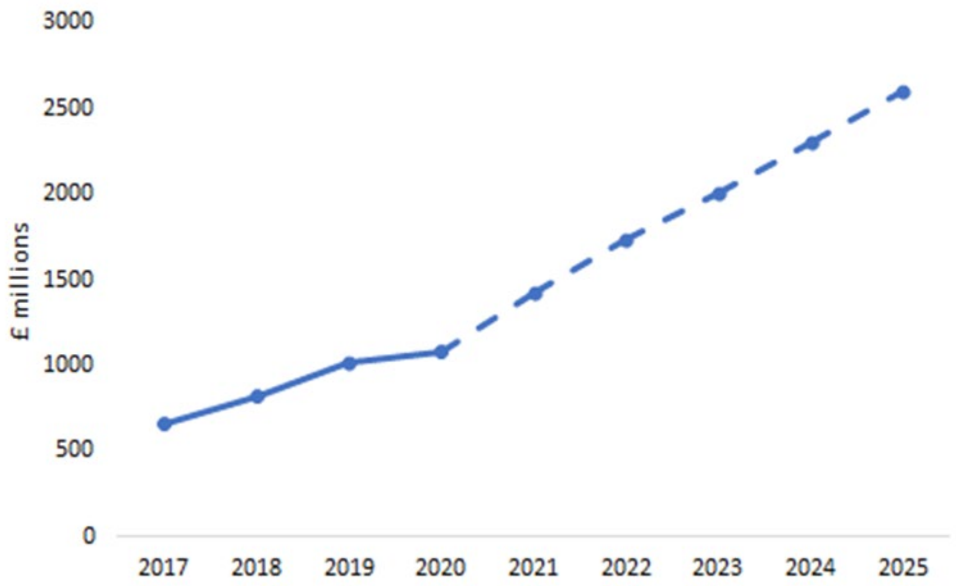
3.1 Current state-of-play of implementation of smart technologies

Current trends in the market for connected products are towards wearables such as “smart watches” and health monitors, toys and childcare equipment, connected automobiles and smart home applications[165].

The “smart home” is a rapidly developing market which can bring substantial safety benefits. In 2017, the global smart home market was worth $43.4 billion, and was expected to reach $91 billion in 2020. The market is expected to achieve an annual growth rate of around 15% by 2024[166].

The smart appliance market, which includes Large Domestic Appliances (LDAs), has been steadily growing[167]. The revenue of the UK smart appliance market has increased from £842m in 2017 and is expected to reach £1,427m in 2021 and £2,605m by 2025 (Figure 3)[168]. Revenue is expected to achieve an annual growth rate of 16.2% between 2021 and 2025. Household penetration is expected to be 9.1% in 2021, increasing to 22.6% by 2025 (Table 5).

Figure 3: Revenue of the UK smart appliance market (in £ million)



[165] OECD (2018) "Consumer product safety in the Internet of Things", OECD Digital Economy Papers, No. 267, OECD Publishing, Paris.
[166] techUK (2020) The State of the Connected Home 2020 Report | Edition 4. techUK reports.
[167] The smart appliance market includes all kinds of connected household appliances, including large (washing machines, ovens, fridge/freezers etc.) and small appliances (microwaves, vacuums etc.).
[168] Statista (2021) Smart Appliances.

Source: London Economics, Statista (2020)
Note: The dashed line represents a forecast (adjusted for the expected image of COVID-19)

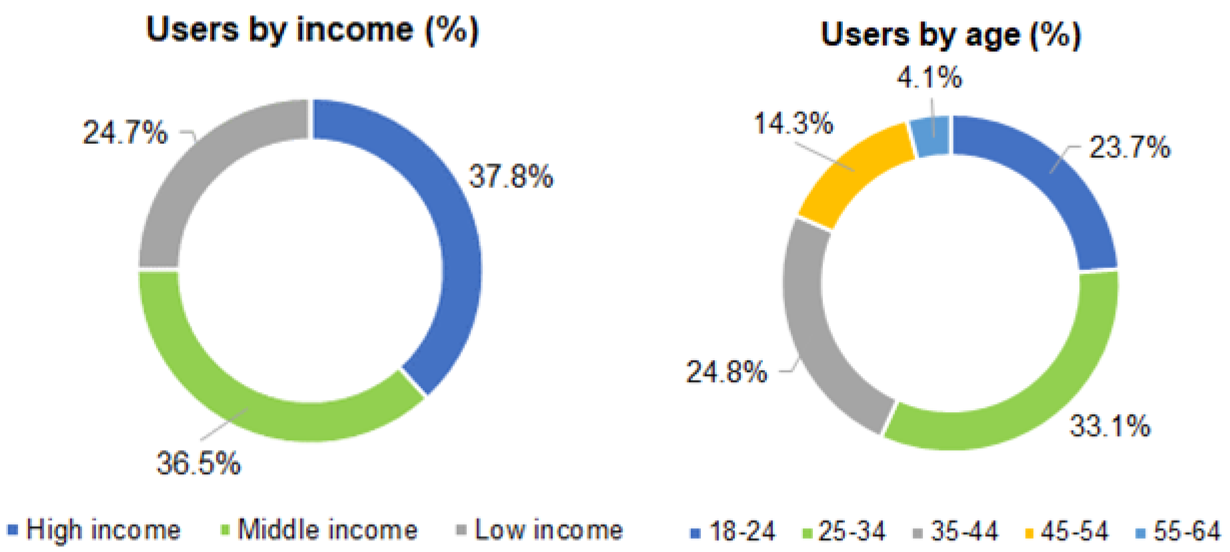
Table 4: Household penetration rate (%)

	2017	2018	2019	2020	2021	2022	2023	2024	2025
Total	3.7%	4.6%	5.8%	7.2%	9.1%	11.4%	14.3%	18.0%	22.7%

Source: Statista (2020)

In 2020, the largest proportion of smart appliance users were in the high income category (37.8%) and the lowest proportion in the low income category (24.7%, see Figure 4). There is also variation in the age of smart appliance users, around 57% of users are between the ages of 18 and 34. A relatively small proportion of smart appliance users are in the age 55-64 category (4.1%).

Figure 4: Users of smart appliances by demographic groups (2020)

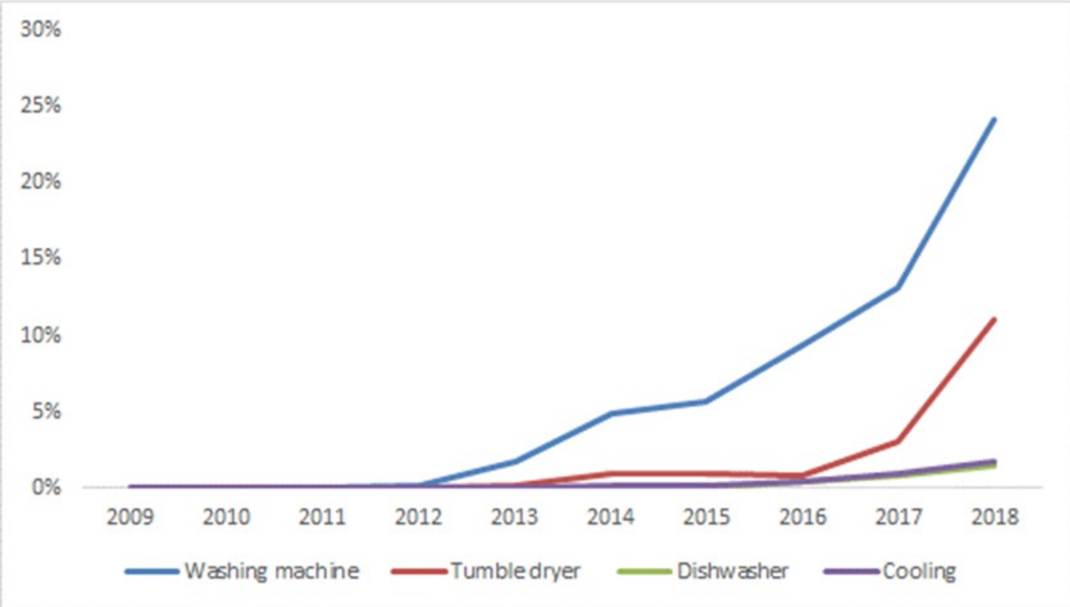


Source: London Economics, Statista (2020)

While connected large domestic appliances currently represent a small part of the smart appliance market, the majority of stakeholders expected that these large appliances will become increasingly connected. Major players in the large domestic appliance market include Samsung, Bosch and LG which have already developed appliances that incorporate IoT and AI technologies within the machine[169]. For example, Samsung and LG introduced smart refrigerators fitted with voice command capability, Wi-Fi connection and cameras that can be accessed remotely[170]. One manufacturer stated that, in their experience, it is laundry appliances, particularly washing machines, that are leading the way in the smart LDA market. This is consistent with research from GfK, which indicates that connected washing machine sales outstrip those of other appliances (see Figure 5).

[169] Emergen Research (2021) Industry Report – Smart Kitchen Appliances Market.
[170] OECD (2017) Benefits and challenges of digitalising production, in The Next Production Revolution: Implications for Governments and Business, OECD Publishing, Paris.

Figure 5: Sales units of LDAs with smart connectivity as a proportion of total sales units



Source: GfK (2018)
Note: Appliances are considered to have smart connectivity if they have either smart diagnosis ability or smart app control. Cooling appliances in this instance includes freestanding or integrated fridges.

3.2 Consumer appetite for smart technologies in LDAs

Consumers are increasingly using smart home devices in their daily lives[171]. For example, the global smart speakers market including Alexa, Google Assistant and Cortana has grown rapidly, from $4.6 billion in 2020 to $7 billion in 2021, achieving a compound annual growth rate of 50%. There has also been a gradual rise in the demand for convenient houses where everything is connected via a smart ecosystem on home appliances[172]. Moreover, several stakeholders indicated that the consumer appetite and interest in smart appliances in the home is increasing. In partnership with GfK, techUK published their latest Connected Home report in 2020 in which 1000 respondents UK respondents were surveyed. TechUK asked about respondents' familiarity with smart home devices and found 79% of respondents indicated they were familiar with at least one smart home device[173]. A driving force behind this greater appetite is changing demographic structure in the housing market as younger people join the property ladder[174].

Indeed, research found that younger consumers are more likely to report higher usage of these devices than older consumers in 2020 (Figure 4). In a sample of 2,001 UK consumers, there was a reported uptake in the usage of smart devices, particularly during the COVID-19 pandemic, where 57% reported an increase in their use of smart devices since the start of the pandemic.

The increases in sales of LDAs with smart capabilities implies an uptake in ownership of smart appliances. Ownership data from Statista reports that the household penetration rate of smart

[171] McKinsey&Company (2015) The Internet of Things: Mapping the Value Beyond the Hype. Executive Summary. McKinsey Global Institute.
[172] Aldossari, M. & Sidorova, A. (2018) Consumer Acceptance of Internet of Things (IoT): Smart Home Context. Journal of Computer Information Systems. 60(6) pp. 507-517
[173] techUK (2020) The State of the Connected Home 2020 Report | Edition 4. techUK reports.
[174] Aldossari, M. & Sidorova, A. (2018) Consumer Acceptance of Internet of Things (IoT): Smart Home Context. Journal of Computer Information Systems. 60(6) pp. 507-517

home appliances was around 5% in 2018 and 7% in 2020 (Table 4)[175]. The reported ownership rate of smart LDAs in particular (ovens and washing machines) in a consumer survey was around 2% in 2018[176]. In 2021, 5% of respondents reported ownership of a smart washing machine, and 1% reported ownership of a smart oven in an OPSS consumer survey[177]. Despite this, over 20% of consumers in the survey reported that they were planning or interested in buying a smart oven or a smart washing machine[178]. A representative of a consumer group noted that they consider market penetration to be high so in the future consumers might have a smart appliance even if they did not necessarily want one initially.

3.2.1 Perceived benefits

Smart home technology can offer opportunities for households but the evidence suggests that consumers may not consider the major selling-point of smart technologies to be safety[179]. There is little evidence in the literature which suggests the extent to which consumers consider safety when purchasing their appliances. For example, a study conducted by Kantar for OPSS found that consumers rarely considered safety benefits in their purchasing decisions[180].

Indeed, several stakeholders raised the potential issue of how manufacturers can sell the safety benefits to the consumer. Stakeholders typically noted that manufacturers may be hesitant to alert their consumers of potential safety hazards by marketing the safety benefits of the smart appliance. Therefore, to increase consumer appetite for smart appliances, manufacturers need to find what a representative of manufacturers described as the ‘hook’ for consumers. They also noted that some attractive features of the smart appliance, such as the ability to start the machine remotely while away from the house might be limited, for safety or other reasons, so this makes it more difficult to attract consumers to these products. Another consumer organisation reported that they believe that in the long term there will be higher demand, but in the short to medium term there will still be resistance amongst consumers.

According to evidence in the literature, some of the benefits consumers do consider are energy savings, convenience, performance, and compatibility with other devices[181][182]. In addition, stakeholders pointed out that consumers’ increasing consciousness of energy efficiency, and the cost impacts of energy consumption, might increase the attractiveness of connected LDAs. The Government is actively supporting the transition to a smarter energy system, a key feature of this is demand-side response (DSR). DSR can help consumers save money and energy by enabling consumers to use electricity when it is plentiful and cheaper, for example at night. A key enabler of this is the rollout of smart meters. For example, in 2019, there were 15.6 million smart and advanced meters operating in homes and businesses across Great Britain, thus demonstrating that many households are considering energy efficiency. This transition towards energy efficiency in the home could be a key driver in the uptake of smart LDAs in the home if they can offer energy saving features. For example, smart LDAs might better enable consumers to harness the full potential of DSR. This may also encourage more consumers to

[175] The smart appliance market includes all kinds of connected household appliances, including large (washing machines, ovens, fridge/freezers etc.) and small appliances (microwaves, vacuums etc.).
[176] Aldossari, M. & Sidorova, A. (2018) Consumer Acceptance of Internet of Things (IoT): Smart Home Context. Journal of Computer Information Systems. 60(6) pp. 507-517
[177] OPSS (2022) Product Safety and Consumers: Wave 2
[178] Aldossari, M. & Sidorova, A. (2018) Consumer Acceptance of Internet of Things (IoT): Smart Home Context. Journal of Computer Information Systems. 60(6) pp. 507-517
[179] BEIS (2020) Consumer attitudes to product safety Research report. BEIS Research Paper Number 2020/032.
[180] Ibid.
[181] Wilson, C., Hargreaves, T. & Hauxwell-Baldwin, R. (2014) Benefits and risks of smart home technologies, Energy Policy, Volume 103, Pages 72-83.
[182] Wang, X., McGill, T. & Klobas, J. (2018) I Want It Anyway: Consumer Perceptions of Smart Home Devices. Journal of Computer Information Systems 60(5) pp. 1-11

connect their appliances. Perceived risks tend to centre around the privacy and security of consumer data. In a study conducted by Citizens Advice, around 72% of respondents stated that they worried about how their data is used and shared. Respondents were more open to the idea of sharing their data provided there was complete transparency and companies sought consent before consumer data was shared[183]. This echoes the suggestions of several stakeholders on best practices for manufacturers when it comes to accessing consumer data from connected appliances. In a sample of 2,001 UK consumers in the DCMS survey, consumers also reported a strong appetite for security features in their smart devices to protect their data. Most agreed or strongly agreed that smart devices should have embedded cyber-security features (88%)[184].

3.3 Existing standards and regulations

Standards and regulations can have an impact on the adoption and implementation of smart technologies in LDAs. Standards and regulations are required to ensure the safety of consumer products. The main challenge in the regulatory space of connected products is the ability of a regulatory regime to keep up with the pace of technological development[185]. There are, however, existing standards and regulation both in development and in place that are relevant to smart appliances.

In the UK, there are ongoing developments in the standards and regulatory space related to home appliances and the Internet of Things (IoT). 'Energy Smart Appliances'[186] are considered to be key enablers in facilitating a low carbon energy system, which is an important element of the Government's Clean Growth Strategy[187]. The Government is proposing to set regulatory requirements for energy smart appliances based on the policy principles of:

- Grid stability: the prevention of outages on the grid caused by inappropriate operation of Energy Smart Appliances.
- Cyber security: the appropriate protection of energy smart appliances from unauthorised access.
- Interoperability: the ability of Energy Smart Appliances to work seamlessly with other devices and service providers, ensuring consumers can switch between different commercial offers and technology choices without having to replace their device or lose core functionality.
- Data privacy: the secure transmission and storing of data on the device or any controlling party.

The Government aims to provide clear minimum requirements for smart appliances and a basis for enforcement as well as align standards internationally[188]. In May 2021, the British Standards Institute published two new Publicly Available Standards (PAS) in relation to the

[183] An important caveat to note is that the sample size in this survey was fairly small (61 respondents from the UK public).
[184] DCMS (2021) Consumer Attitudes Towards IoT Security. Ipsos MORI.
[185] OECD (2018), "Consumer product safety in the Internet of Things", OECD Digital Economy Papers, No. 267, OECD Publishing, Paris.
[186] An Energy Smart Appliance is defined as a communications-enabled device able to respond automatically to price and/or other signals by modulating or shifting its electricity consumption. BSI Energy Smart Appliances Programme
[187] BEIS (2018) Consultation on Proposals regarding Smart Appliances.
[188] BEIS (2018) Consultation on Proposals regarding Smart Appliances.

principles outlined above, which were sponsored by BEIS and the Office for Zero Emissions Vehicles (OZEV)[189].

In March 2018, the Department for Digital, Culture, Media and Sport (DCMS) published a Code of Practice for consumer IoT security. The Code of Practice sets out thirteen guidelines which bring together what is considered as good practice in IoT security for manufacturers and other industry stakeholders to follow[190]. The Code of Practice applies to any consumer IoT products that are connected to the internet. The Code of Practice includes guidelines such as no default passwords, software must be kept updated, and security-sensitive data must be securely stored[191]. Following this and the adoption of the European standard ETSI EN 303 645[192], DCMS are planning to legislate to create a new robust scheme of regulation to ensure that products made available to UK consumers comply with a minimum baseline level of cyber security[193].

Other standards or regulations that were mentioned during stakeholder consultations included: the Radio Equipment Directive[194] and GDPR[195] (summarised below).

Further regulations are provided in Table 6 below.

Table 5: Existing standards and regulations relevant to smart appliances

Standard/regulation	Coverage	Description
The Radio Equipment Regulations 2017, which implements Directive 2014/53/EU on Radio Equipment	UK/EU	This regulation and directive covers any radio interfaces (including Wi-Fi) that could be used in domestic appliances. It is a total safety directive covering all aspects of safety for appliances in scope. For example, this Directive requires that the compliance of the appliance is not compromised when software is uploaded[196]. The European Commission intends to increase the scope of the Directive to cover more elements of cyber security.
BS EN 60335-1: Household and similar electrical appliances – Safety – General Safety Requirement	UK	Provides best practice recommendations for safety testing household and similar electrical appliances. The standard applies to manufacturers, suppliers of components, Trading Standards,

[189] BSI Group (2021) Energy Smart Appliances Programme.
[190] DCMS (2018) Code of Practice for consumer IoT security.
[191] Ibid.
[192] ETSI (2020) Cyber Security for Consumer Internet of Things: Baseline Requirements, Final draft ETSI EN 303 645.
[193] DCMS (2021) Government response to the call for views on consumer connected product cyber security legislation
[194] European Commission (2021) Radio Equipment Directive (RED), Internal Market, Industry, Entrepreneurship and SMEs.
[195] European Union (2016) REGULATION (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation).
[196] European Commission (2020) Report on the safety and liability implications of Artificial Intelligence, the Internet of Things and robotics.

		regulatory bodies, and Consumer groups. Currently this does not consider the issues of cyber-attacks or data security issues in smart appliances. The current requirement of this standard also limits the remote control of appliances i.e. the ability to switch on appliances such as ovens remotely is very restricted[197].
IEC 60730 -1 – Safety standard – Automatic electrical controls for household and similar use		The safety standard defines the test and diagnostic methods that ensure the safety of household appliances with embedded hardware and software.
The Data Protection Act 2018, EU General Data Protection Regulation (GDPR)	UK/EU	The Data Protection Act 2018 is the UK's implementation of the General Data Protection Regulation (GDPR). Manufacturers of smart appliances will have to store data securely such that it complies with GDPR.
The General Product Safety Regulations 2005, which implements the General Product Safety Directive	UK/EU	This regulation and directive complements sector specific legislation. This requires all consumer products need to be safe. The Directive specifies that a safe product should consider the effect on the safety of other products. Therefore, for a connected device that is intended to be connected to other smart devices, it should be foreseeable that this could affect the safety of these devices under this Directive.
Electrical Equipment (Safety) Regulations 2016	UK	The Regulations apply to all electrical equipment that is designed or adapted for use between 50 to 1,000 volts (in the case of alternating current) and 75 to 1,500 volts (in the case of direct current). The Regulations apply to domestic electrical equipment and equipment intended for workspaces. The Regulations implemented EU Directive (2014/35/EU), commonly called the Low Voltage Directive.
European Telecommunications Standards Institute (ETSI) EN 303 645[198]	Europe/Global	In February 2019, ETSI launched the first globally applicable industry standard on internet connected consumer devices (ETSI Technical Specification 103 645).

[197] OPSS (2022) Safety of Smart Domestic Appliances. BIES research paper
[198] Datta Burton, S., Tanczer, L., Vasudevan, S., Hailes, S. & Carr, M. (2021). The UK Code of Practice for Consumer IoT Security: 'where we are and what next'. The PETRAS National Centre of Excellence for IoT Systems Cybersecurity. DOI: 10.14324/000.rp.10117734

		Following on from this, in June 2020, European Standard 303 645 was published which establishes a baseline for connected consumer devices and provides a baseline for future IoT product certification schemes.

3.4 Barriers to implementation of smart technologies in LDAs

3.4.1 Data privacy

One of the key barriers for manufacturers to implement smart technologies in LDAs is cyber security and data protection concerns. Cyber security refers to the protection of systems, networks, and programs to prevent hacking. Data protection refers to how personal information is used by organisations, businesses, or governments. This relates to issues such as data ownership and data privacy. All of the stakeholders that have been consulted so far noted that a substantial barrier to the implementation of smart technology in LDAs and consumer demand for these appliances is cyber security and data privacy issues.

The increasing awareness of data protection and cyber security can create a lack of trust in connected devices. With the introduction of the General Data Protection Regulations (GDPR), data privacy is likely to be an increasing issue in the connected space and be a source of hesitation amongst consumers in their demand for smart appliances in their home[199]. Sovacool et al. (2020) conducted a study amongst stakeholders in smart technology and found that "privacy, security and hacking" was the primary risk or barrier for 81% of respondents[200]. Similarly, a consumer study by Traverse (2018) for Citizens Advice found that the majority of respondents were concerned about what data would be collected from them, how this data would be used and how this affected their risk of cyber-attacks[201]. The key takeaway was that there should be transparency over data sharing and the ability to opt in or out at the consumer's discretion[202]. In a consumer survey of 1000 UK adults, techUK found that 53% were concerned about data privacy[203].

To maximise their efficiency and usability, smart products need to collect and transmit a lot of data[204]. However, devices that share data through an internet source may be more vulnerable to cyber-attacks, especially in a network of smart devices[205]. A cyber-attack on individual appliances could have safety implications. For example, if a hacker gained access to the machine's controls, they could disable the machine or repeatedly switch appliances on and off leading to overheating[206]. Such security risks can lead to risks of serious harm: for example, in the vehicle market, Chrysler recalled over a million vehicles in 2015 whose software presented a vulnerability flaw which would allow hackers to remotely control the cars, cut the brakes, or drive them off the road[207]. The potential of harm from cyber security risks is something that the

199 techUK (2020) The State of the Connected Home 2020 Report | Edition 4. techUK reports.
200 Sovacool, B. & Furszyfer Del Rio, D. (2020) Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. Renewable and Sustainable Energy Reviews, Volume 120
201 Traverse (2018) The future of the smart home: Current consumer attitudes towards Smart Home technology.
202 Ibid.
203 techUK (2020) The State of the Connected Home 2020 Report | Edition 4. techUK reports.
204 The BSI group (2021) Energy Smart Appliances Programme.
205 Alaa, M., Zaidan, A., Zaidan, B., Talal, M. & Kiah, M. (2017) A review of smart home applications based on Internet of Things, Journal of Network and Computer Applications, Volume 97,
206 OPSS (2022) Safety of Smart Domestic Appliances. BIES research paper
207 CNN Tech (2015) Chryslers can be hacked over the Internet.

manufacturer will have to consider[208]. An interviewed consumer organisation noted that an important lesson that has emerged recently is that Wi-Fi routers do not always protect users' data[209]. This is usually trusted amongst consumers, so this needs to be considered if smart appliances would be connected via routers.

The second-hand market also presents a particular challenge to protecting consumers' data security if the appliance can store the personal information of previous users. Under the provisions of General Data Protection Regulation (GDPR), manufacturers will have to ensure the appliance can be reset to factory settings when it moves to a new user[210]. Furthermore, an appliance that is linked to a server controlling several other appliances, or serves as a hub to other smart appliances, may present an even greater risk[211]. In the case of a smart home, for example where everything is connected, it could be possible for hackers to identify the status of the home at all times by monitoring the usage of appliances[212]. In Sovacool et al. (2020)'s study, one stakeholder notes that a connected appliance, which might initially be considered to be low risk in terms of hacking, could provide a gateway into the wider home security system[213]. One representative of manufacturers suggested that connections via app could represent a security risk. A consumer organisation suggested that the local network consumers' appliances are connected to can be unsecure, for example Wi-Fi routers.

Another barrier to the implementation of smart technology in LDAs is ambiguity about data ownership. There is a lack of clarity on the ownership of machine-generated data and further uncertainty around the ownership of 'non-personal' data, such as that generated from the usage of a domestic appliance[214]. Ownership of such data, therefore, may be a barrier to data sharing from the perspective of consumers who are concerned with their data privacy, as well as presenting challenge to manufacturers. Several consumer groups noted that consumers might have reservations about the technology if they view it as 'spying' or invasive. A barrier for manufacturers would then be helping consumers to understand what the connected device means for their data, that is, how it is being used, how they can stop access to the data and the ramifications of sharing data. One consumer organisation noted that some people are very sceptical of data sharing already and gave the example of consumer's concerns over smart speakers listening in their home. In terms of regulation, a representative of manufacturers felt that GDPR could potentially limit the impact of safety enhancing connectivity benefits.

On the other hand, several stakeholders noted that as long as manufacturers are up-front and transparent regarding the data that they are collecting and seek the correct permissions from the consumer, it may not pose a large barrier. Several stakeholders, including manufacturers, also argued that data privacy may not pose a big issue because data collected on the usage and performance of an appliance such as a dishwasher or washing machine is not "protected" data e.g. data relating to finances or health. Several stakeholders also stressed the importance that data should only be collected after receiving clear consent from the consumer, who should have full knowledge of how the data is used and the right to revoke the use of their data at any time.

208 OPSS (2022) Safety of Smart Domestic Appliances. BIES research paper
209 Which? (2021) Millions of people in the UK at risk of using insecure routers.
210 OPSS (2022) Safety of Smart Domestic Appliances. BIES research paper
211 Ibid.
212 Sovacool, B. & Furszyfer Del Rio, D. (2020) Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. Renewable and Sustainable Energy Reviews, Volume 120
213 Ibid.
214 European Commission (2020) Report on the safety and liability implications of Artificial Intelligence, the Internet of Things and robotics. Brussels.

In terms of safety of the consumer, one consumer organisation notes that greater connectivity can make people more susceptible to cyber security risks, for example vulnerability to hacking.

3.4.2 Technological barriers

There is limited literature on the technological barriers for LDAs in particular. The barriers outlined in the following, such as issues around interoperability and how willing and able consumers are to connect their smart products, were mentioned by stakeholders as potential barriers that were also relevant for manufacturers of smart LDAs.

Interoperability enables different devices and systems, manufactured by different brands, to work with one another or "talk the same language"[215]. Achieving interoperability will be essential for the deployment of IoT and other connected products[216]. According to a study by McKinsey, interoperability is required for 40% of the potential value across IoT applications[217]. A lack of interoperability limits the usefulness of connected devices and limits consumer demand for connected or IoT-based products. Moreover, stakeholders pointed out that open standards (which can facilitate interoperability and data exchange among different systems) have benefits for consumers, such as with Samsung or LG product suites.

Currently, the barrier to interoperability is driven largely by brands' competitive agenda and hope of gaining market share[218]. Interoperability is not only a challenge for integrating different appliances, but it will also require cooperative relationships between different manufacturers when individual appliances need to be replaced without disrupting the whole connected system of appliances, for example interoperability will be particularly important in the context of a 'smart home'[219]. Several stakeholders noted that interoperability might be a barrier to the implementation of smart technologies in the home. One product safety expert noted that if it is difficult to integrate systems between different brands of products, then the data collected might not be compatible with different manufacturers.

The reliance on connectivity, for example through Wi-Fi, in IoT technologies may raise additional challenges. For example, for appliances that are remotely controlled through a central hub such as a smart phone, this relies on the smartphone having internet connection. If the connection fails, this can disable the functionality of the network of appliances that are controlled through the smartphone. For example, if a connected fire alarm loses its connection and thus fails to alert the user of a fire through their smart speaker or smartphone. Having several connected devices also requires a substantial amount of data sharing and this can create a load on a network, this therefore relies on a strong network architecture that can support the amount of traffic from many devices.

One stakeholder also raised the concern that in the event of an appliance failing, it could trip the Residual Current Device (RCD). If this disables the internet connection, then the consumer or manufacturer will potentially not receive a notification.

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[215] Internet Society (2015) The Internet of things: an overview. Understanding the Issues and Challenges of a More Connected World.

[216] European Commission (2020) Report on the safety and liability implications of Artificial Intelligence, the Internet of Things and robotics. Brussels.

[217] McKinsey&Company (2015) The Internet of Things: Mapping the Value Beyond the Hype. Executive Summary. McKinsey Global Institute.

[218] OECD (2018) OECD (2018), "Consumer product safety in the Internet of Things", OECD Digital Economy Papers, No. 267, OECD Publishing, Paris.

[219] Shin, J., Park, Y. & Lee, D. (2018) Who will be smart home users? An analysis of adoption and diffusion of smart homes. Technological Forecasting and Social Change, Elsevier, 134(C), pp. 246-253

Furthermore, the safety benefits of smart domestic appliances commonly rely on consumers connecting their appliance to an internet source. This would involve connecting their appliance to a Wi-Fi network or a smartphone through an app, for example, as well as opting in to share their data and receive communication from the manufacturer. These challenges were raised by several stakeholders. TechUK found that owners of connected devices, smart LDAs, including smart ovens/hobs and smart washing machines, were the category with the lowest of connections to the home Wi-Fi (44%)[220]. A consumer survey carried out on behalf of DCMS in 2020[221] found this figure to be lower, with around 25% of consumers with smart domestic appliances connect their appliance to the internet. The connection rate, however, varied by appliance: for cookers/ovens, washing machines and tumble dryers, the connection rate was 24%. For dishwashers and fridge/freezers the connection rates are higher at 34% and 40%, respectively.

Stakeholders raised other technological barriers such as the concern that manufacturers may not always have the knowledge to develop smart technologies in their appliances themselves and so outsource for this, which could result in the manufacturers knowing less about the potential risks. A representative of manufacturers also mentioned that, when considering the long life of large domestic appliances[222], time was a barrier, such that even if connected technology was widely implemented now, it would take years to go through the replacement cycle, so the benefits would be delayed.

3.4.3 Regulatory barriers

Standards and regulations for connected technologies

The research suggests that consumers are generally well-protected by robust product safety regulations and standards[223]. The development of new technologies, however, brings added dimensions to the overall risk of a product for consumers. One view is that the current product safety and liability regimes are adequate for IoT products, for example in a 2015 report, the Alliance for Internet of Things Innovation (AIOTI)[224] state that new regulation is not necessary for most IoT products. However, a concern is that the pace of technological development may be a challenge for new regulations to keep up with. A report by the European Commission states that a large portion of the EU product safety framework was written prior to the use of emerging technologies such as AI and IoT in products, so may not address the most recent challenges[225].

A key challenge for the IoT industry is balancing having sufficient regulation in place to ensure product safety, without stifling technological innovation. An IoT product is inherently complex which might result in a long period of implementing regulations and designing standards. Especially since, as connected products, they are increasingly global, this requires a coordinated response globally. One stakeholder raised the concern that standard setting and regulation might create inequalities between manufacturers, such that some manufacturers are less heavily regulated than others which might have competitive impacts. Therefore, they emphasised the need for harmonised standards and regulations globally. One complexity is

[220] techUK (2020) The State of the Connected Home 2020 Report | Edition 4. techUK reports.
[221] RSM UK (2020), Evidencing the cost of the UK Government's proposed regulatory interventions for consumer IoT: Technical Report. DCMS.
[222] Which? (2021) The best and worst large appliance brands: new Which? survey results revealed
[223] European Commission (2020) Report on the safety and liability implications of Artificial Intelligence, the Internet of Things and robotics. Brussels.
[224] AIOTI (2015) AIOTI Working Group 4 – Policy Report.
[225] European Commission (2020) Report on the safety and liability implications of Artificial Intelligence, the Internet of Things and robotics. Brussels.

the definition of IoT products as goods and services are treated differently in regulatory regimes[226]. It is argued that IoT brings an interaction between the two, while a product in principle is a physical good, something that provides data through a system or offers repairs through remote system updates could be argued to be a service to consumers[227].

Certain academic legal stakeholders are suggesting that current EU regulations might not be fit for purpose. Liability frameworks in the EU rely on the application of the harmonised Product Liability Directive (85/374/EEC) and other non-harmonised national liability regime. The Product Liability Directive ensures strict liability of the producer in damage caused by a defect in their product, and in the event of harm the user is entitled to compensation. In a report the European Commission states that while in principle existing liabilities laws are able to cope with new technologies, it is possible they could reduce the effectiveness of these frameworks and risk victims not being adequately compensated. One stakeholder mentioned that bringing IoT technology into LDAs might have the effect of complicating liability due to the integration of several supply chains and manufacturers, for example with third party software. These legal uncertainties could reduce investment and thus form a barrier to innovation.

Regulations as a factor in adoption/implementation of smart technologies for LDAs

Several stakeholders noted that regulation was an important element in the decision-making to adopt connected technologies. A number of stakeholders mentioned the role of the Department for Media, Culture and Sport (DMCS) in the legislation of connected products, including the legislative proposal ‘Secure by Design’ which is related to connected goods.

One product safety expert noted that standards setting is more reactive than proactive, such that there is always a catch-up period for standards to meet the latest requirements of technologies. They noted that one such lag at the moment is around the issue of cyber security. However, as the market for large domestic appliances has relatively few manufacturers, it should not take a very long time to develop standards related to those specifically. That said, a representative of first responders mentioned a case where after a safety risk regarding the highly flammable backing to fridge/freezers was flagged, it took around 8 to 10 years to change the manufacture of this component.

Another expert also noted that current safety regulations are based more on the physical attributes of products and how they perform, so additional regulation will be necessary for technologies integrated into the product, but in their view, this will not be a barrier.

Stakeholders were also invited to comment on what more standard makers, regulators or manufacturers could do to ensure smart technologies enhance the safety of LDAs. Several stakeholders held the view that these bodies are doing well to harness the potential of smart technology to increase safety. Several stakeholders were also able to identify areas where more could be done. For example, several noted that it requires coordination across many bodies and between different government departments to ensure smart technologies enhance the safety of LDAs. One representative of first responders noted they were concerned that there can be a lack of consensus in standards making. Another product safety expert raised a concern that large manufacturers are key stakeholders in the decision making of standards and so may influence the standards for their interests. Several stakeholders noted that enforcement is currently too weak, especially with white goods, and that without the right enforcement, regulation will be unsuccessful.

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[226] Ibid.
[227] OECD (2018) OECD (2018), "Consumer product safety in the Internet of Things", OECD Digital Economy Papers, No. 267, OECD Publishing, Paris.

A number of other suggestions were made by stakeholders on what more could be done by standard makers, regulators, and manufacturers. One stakeholder suggested that manufacturers and retailers would be more resistant to further regulation and instead would rather have (voluntary) standards implemented. However, one caveat to this, which was raised by a consumer organisation, was that many would not follow voluntary guidelines. Another representative of first responders suggested that manufacturers and regulators need to work together to relay clear communication with consumers in the event of a recall to prevent any further harm to consumers.

Another area that was mentioned was the need for standards to be developed to ensure interconnectivity between different brands, as well as clear and intuitive protocols on how these devices connect. A consumer organisation also suggested that assurance schemes could be an effective way of regulating markets and improving trust. Moreover, several stakeholders noted that an important step in the regulatory space is to define what constitutes ‘connected’ or ‘smart’ appliances, as there is currently no standardised definition.

Finally, stakeholders pointed out that there was frequently a ‘grey area’ regarding where it was permissible for manufacturers to intervene in a consumer product (e.g. through software updates) once it was in consumers’ hands. A representative of LDAs pointed out that it would be useful to have clarity regarding what steps manufacturers could take in the interests of product safety, without breaching consumer rights.

3.4.4 Other barriers

Cost efficiency

Cost was mentioned by several stakeholders as a barrier to the implementation of smart capabilities. A representative of manufacturers noted that the cost of integrating smart technologies might be very expensive, however, it is certainly more suitable for large domestic appliances as they typically have a higher cost relative to small domestic appliances. Several stakeholders also raised the concern that it is likely that this cost will be passed on to consumers. A representative of manufacturers noted that there will also be additional costs to the manufacturer for the monitoring and processing of data collected from connected appliances.

Consumer engagement

Consumer engagement was also a barrier identified by several stakeholders. Several stakeholders noted that even if smart technology in LDAs was widely implemented, consumer engagement could still be low. A product safety expert noted that even among those who had smart appliances, the majority of users would be unlikely to have it connected to an internet source. One representative of manufacturers provided the example that out of the consumers with smart TVs, only around 50% of them are connected to the internet despite the obvious benefits (e.g., catch-up TV, greater choice), therefore it could be expected even fewer would connect smart appliances, as the benefits are less clear. They suggest a type of connectivity that is automatically connected, and allow users to disconnect if they wish, would be better to ensure all users benefit from the smart capabilities of the appliance, particularly the safety-improving features.

Moreover, several stakeholders pointed out that consumers may resist aspects of predictive maintenance and condition monitoring. From a commercial perspective, representatives of manufacturers and retailers pointed out that if consumers were contacted by manufacturers to inform them that their machine is about to breakdown and needs a repair, they may question its reliability. One representative of LDA manufacturers suggested that users would be more likely to be attracted to this feature from the point of view of the impact on longevity of the machine rather than safety, as consumers believe their appliances are inherently safe.

Moreover, smart technologies may lead to unintended consequences. For example, there is a risk that installing additional components in the machine will introduce more malfunction risk. One product safety expert raised concerns that predictive maintenance may dampen a user's perception of safety and thus become complacent when using their appliance. In a study of 2,000 adults by Smart Home Week, 40% of adults believed that home insurance should be reduced if they had made steps towards investing in smart technology in their home[228]. This implies that consumers recognise the safety benefits of smart technology in the home, but there is also the risk this heightened perception of safety could lead to complacency.

Finally, a representative of manufacturers noted that using smart capabilities for predictive maintenance or recalls would still to some extent rely on consumer behaviour to act on the information, which is a largely uncontrollable factor. For example, in an OPSS survey exploring consumer attitudes to product safety, 19% of consumers who reported that they had received a recall notification took no action. This could be indicative of the proportion of people that would also not respond to maintenance notifications[229].

Barrier to adoption of smart technologies due to digital exclusion

Digital inclusion covers the digital skills, connectivity and accessibility/usability of digital products or services and can be a barrier to adoption.[230]

The price of LDAs which incorporate smart technology was cited by one stakeholder as a barrier to the consumer demand for these appliances. Many stakeholders pointed out that smart technologies were typically observed in 'premium', or higher-priced, products. This could present a risk of potentially 'leaving behind' low income consumers or those who have pre-furnished accommodation[231]. One manufacturer suggested that in the future, more expensive connected appliances are likely to be more reliable than less expensive, unconnected appliances.

Another key barrier to adoption of smart technologies is usability. There is a risk that some groups will be 'left behind' if they struggle to use this technology[232]. Studies show that for older groups in particular, a barrier to the adoption of smart technology can be apprehension around the usability and the lack of support once this is in place[233].Representatives of consumer organisations pointed out that there are existing concerns regarding data privacy and security of smart technologies, discussed previously. These concerns may be magnified in the case of consumers who are digitally excluded[234] or lack confidence or in positions of vulnerability which make them less able to understand the uses of their data or to advocate for themselves[235].

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228 Smart Home Week (2019) 2019 Smart Home Survey.
229 OPSS (2020) Consumer attitudes to product safety.
230 NHS definition of digital inclusion
231 Age UK (2018) Digital Inclusion Evidence Review
232 Sovacool, B. & Furszyfer Del Rio, D. (2020) Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. Renewable and Sustainable Energy Reviews, Volume 120
233 Vaportzis, E., Clausen, M. & Gow, A. (2017) Older Adults Perceptions of Technology and Barriers to Interacting with Tablet Computers: A Focus Group Study. Front Psychol. 8(1687)
234 Age UK (2018) Digital Inclusion Evidence Review
235 Scie (2019) Safeguarding adults: sharing information.

4 Calculating the value of smart capabilities

The literature review and stakeholder consultation have found a range of capabilities and safety benefits of smart technology. To complement this research, quantitative analysis, presented in this section values two types of benefit from adopting smart appliances. That is, the value of avoided harms (e.g. injuries, fatalities and property damage) from fewer incidences of fires and a valuation of the potential uplift in returns for product recalls. Through measuring these outcomes, the smart capabilities that the modelling seeks to value are condition monitoring and predictive maintenance (e.g. turning off devices at certain temperatures and forewarning the consumer or manufacturer of an identified fault) and the ability to send recall notifications to customers directly via the appliance (or associated app).

4.1 Modelling fire prevention and avoided harms from use of smart technologies

4.1.1 Methodology

Scope of the modelling

Our research suggests that condition monitoring and predictive maintenance capabilities may be able to prevent fires through providing a lead time to product failure. Forewarning the consumer and manufacturer of problems with components allows problems to be rectified in advance of failure and/or fire. Smart capabilities can also shut down the appliance entirely if a fault is identified to prevent exacerbating hazards like fires. Furthermore, if fires do start, connectivity to other devices, such as a smoke alarms or smart speakers, gives consumers enough warning time to exit their property to a place of safety, preventing injuries and fatalities. For example, there is a smoke alarm available on the market which connects to the emergency services directly, facilitating a rapid response.[236]

Therefore, the analysis considers two mechanisms through which smart appliances could avoid harm. Firstly, condition monitoring and predictive maintenance would be expected to **reduce the likelihood of a fire starting at all**, avoiding injuries, fatalities and damage arising as a result. In addition, connectivity to smoke alarms or smart speakers has the potential to **reduce the likelihood of severe harms arising from appliance fires**, since consumers have time to take action, evacuate and limit impact on their life and property.

Note that our modelling approach is restricted to fires arising from faulty appliances and excludes fires arising from misuse. This is because experts representing both manufacturers and consumer organisations have suggested that consumer behaviour leading to unsafe situations is very difficult to mitigate against because of its unpredictable nature, even with smart capabilities. For example, some product safety experts suggested that whilst smart technology might be able to mitigate against some careless behaviour, smart appliance users may become complacent regarding safety, and so act more carelessly.

Previous research also suggests that human inattention can contribute to fires. For example, in the previous Safety of Smart Domestic Appliance report for OPSS[237], a modelling exercise was carried out to estimate the potential increase in unattended fires as a result of time shifting appliances. For this reason, the analysis will only include fires that are caused by faulty

[236] https://simplisafe.co.uk/smoke-detector
[237] OPSS (2022) Safety of Smart Domestic Appliances. BEIS research paper.

appliances or leads[238], since we can be confident in the assumption that condition monitoring and predictive maintenance could prevent some of these fires. Given the uncertainty around whether fires arising from other causes such as misuse of appliances or careless behaviour would be prevented with smart capabilities, we adopt a conservative approach and exclude these fires from the analysis.

To quantify the number of avoided faulty appliance fires and associated harms as a result of smart take-up, an avoided cost approach is used, since it provides the most natural way to estimate these types of benefit.

The analysis is carried out separately for each type of LDA focussed on in this research, specifically:

- Cookers/Ovens,
- Washing machines,
- Tumble dryers,
- Washer/Dryers,
- Dishwashers, and,
- Fridge/freezers.

Modelling Scenarios and Key Assumptions

The current state of play on the numbers of smart appliances and likelihood of fires is analysed in a baseline scenario, using the latest data on the levels of smart take-up in LDAs and on the incidences of fires (for 2019/20) from the Home Office.

To estimate how many appliances are in circulation, we multiply the number of households in the UK (27.8 million)[239] by the proportion of households who own these products taken from either the ONS (for tumble dryers and dishwashers)[240], Statista Global Consumer Survey (for cooker/ovens and fridge/freezer)[241] or the UK Energy Research Data Centre (for washing machines and washer/dryers)[242].

Table 6: Household ownership of appliances

Appliance	Proportion of households who own appliance	Source
Cookers/Ovens	91%	Statista Global Consumer Survey
Washing Machines	80%	UK Energy Research Data Centre

238 Home Office Fires data provide this breakdown.
239 ONS (2020) Families and Households data by household size, regions of England and UK constituent countries.
240 ONS (2021) Family spending workbook 4: expenditure by household characteristic.
241 Statista (2021) Global Consumer Survey
242 UK Energy Research Data Centre data.

Tumble Dryers	57%	ONS
Washer/Dryers	15%	UK Energy Research Data Centre
Dishwashers	50%	ONS
Fridge/Freezers	140%*	Statista Global Consumer Survey

Note: *The 140% is broken down into 91% of households that have a refrigerator and a further 49% that have a standalone freezer. Sources were selected based on data availability.

To estimate how many of these appliances have smart capabilities which could reduce harm, we multiply the number of appliances by the rate of smart take-up. In 2019/2020, the average rate of smart take-up was 3.2% for large appliances and is predicted to increase to 4.4% by the end of 2021[243]. This is corroborated by evidence from the second wave of the OPSS consumer survey[244], where 4.5% of respondents said they currently owned or had access to a smart white good in their household.[245]

In addition, experts raised that not all smart appliances currently available on the market include condition monitoring and predictive maintenance technology capable of reducing harm from fires. Analysis of sales data from GfK[246] shows that approximately one quarter of appliances have diagnostic capabilities. This diagnostic technology is the most common in smart fridge/freezers (68.8%), followed by washing machines (29.8%), and least common in smart dishwashers (0.1%) (see Table 8 below).

Table 7: Condition monitoring and predictive maintenance in smart appliances

Appliance	Proportion of smart appliances sold with diagnostic capabilities
Washing Machines	29.8%
Tumble Dryers	8.1%
Washer/Dryers	20.8%
Dishwashers	0.1%
Fridge/Freezers	68.8%

243 Statista Digital Market Outlook.
244 OPSS (2022) Product Safety and Consumers: Wave 2
245 Note that sales data was available to estimate the proportion of appliances with smart capabilities (approximately 14.5% in 2018). However, this was not used in the modelling since this captures sales of appliances rather than ownership. Given that smart products are fairly new to the market, they will make up a larger proportion of recently sold appliances than all appliances out in circulation and so the 14.5% may overestimate the proportion of appliances that are smart.
246 Purchase data from GfK for the period January 2009 to December 2018.

Average	**25.1%**

Source: London Economics analysis of GfK sales data (2018). Note smart diagnostic tools is not defined in the dataset, however we assume this can be used to proxy for condition monitoring and predictive maintenance technology. In the modelling, we apply the cross-appliance average of 25.1% for cookers and ovens since there is no specific data available for this product.

Furthermore, according to a consumer survey carried out on behalf of the Department for Digital Culture Media and Sport (DCMS) in 2020[247], around one quarter of consumers with smart domestic appliances connect their appliance to the internet. The connection rate varies by appliance. 24% of cooker/ovens, washing machines, tumble dryers and washer/dryers are always connected. For dishwashers and fridge/freezers the connection rates are higher: 34% and 40% respectively. These connection rates are also factored into the calculation, as we assume only products that are connected would derive safety benefits.[248]

Below summarises the current state of play in the baseline scenario for each of the appliances analysed.

Table 8: The Baseline scenario

Appliance	Estimated number of appliances in circulation in the UK (All)	Estimated number of connected appliances with smart capabilities in circulation	Estimated number of non-smart or unconnected appliances in circulation	Estimated number of faulty appliance fires in UK in 2019/20
Cookers/Ovens	25.3 million	47,699	25.2 million	240
Washing Machines	22.2 million	50,462	22.2 million	621
Tumble Dryers	15.8 million	9,729	15.8 million	548
Washer/Dryers	4.2 million	6,592	4.2 million	64
Dishwashers	13.9 million	174	13.9 million	204
Fridge/Freezers	38.9 million	339,268	38.6 million	216

Note: Estimates of the number of appliances are rounded to the nearest 100,000. Figures may not sum due to rounding. 2019/20 refers to the financial year April 2019 to March 2020. Home Office Fires data only covers

[247] RSM UK (2020), Evidencing the cost of the UK Government's proposed regulatory interventions for consumer IoT: Technical Report. DCMS

[248] Connection rates have also been estimated by TechUK in their Connected Homes 2020 report – see https://spark.adobe.com/page/xAZEUOfDB4I9E/#vii-connectivity-in-the-home. For the domestic appliances category, it is estimated that 44% of products are connected to home Wi-fi. This estimate was not used in the modelling, however, since the category of "domestic appliances" was not well-defined and we could not split out the rate of connection across the different types of white goods modelled.

England therefore faulty appliance fires for the UK are extrapolated by applying the likelihood of an appliance causing a fire in England to the population of UK appliances (see section 4.1.3 for more information).

This baseline scenario will be compared with four hypothetical alternative scenarios, with different underlying assumptions. The first three scenarios represent a realistic outlook of smart appliance adoption in the near future. The fourth scenario demonstrates the maximum potential of this technology should all consumers adopt smart appliances and new developments in technology be brought to market that are highly effective at reducing fire risk.

The main assumption that is made in the alternative scenarios is around the proportion of appliances that will include the smart capabilities which can reduce the likelihood of fire and/or harms. In all the alternative scenarios, the adoption of this technology is assumed to be higher than in the baseline. This allows us to measure the difference in the number of harms (i.e. harms avoided) if there was greater adoption of smart technology in LDAs. The scenarios range from early adopter situations (using the forecast of smart adoption in LDAs for 2023 2025 and 2030[249]) to a situation where 100% of appliances in circulation have these capabilities (to demonstrate an upper bound of impact).

For the first three alternative scenarios, as per the baseline, we assume that between 24% and 40% of smart appliances are connected. In the fourth scenario (used to demonstrate upper bound impact), we assume that a higher proportion of consumers would connect their appliance, since new developments in smart technology in other areas (like energy) may encourage greater connection rates. Specifically, we assume that any consumers who said their appliance was disconnected or connected intermittently in the DCMS survey[250] would also connect their appliance. Therefore, the connection rates used in the fourth scenario range from 60% to 79%, depending on the appliance.

We also use the same proportions of smart appliances that include condition monitoring as the baseline for the first three alternative scenarios. There is an argument that the proportion of appliances with condition monitoring should increase over the three main scenarios reflecting capability improvements of smart appliances on the market. However, due to data unavailability, it is not clear how this proportion would ‘evolve’ over the three main scenarios. The historical trend of this statistic from GfK data actually falls over time (since there are a growing number of smart appliances on the market and most of these don’t include condition monitoring). Therefore, we keep this assumption constant across the three main scenarios. Scenario 4 is used to show what happens if this assumption is maxed out to 100% (i.e. all smart appliances have condition monitoring and predictive maintenance technology). It could be said this a very strong assumption, but as we mention above this is an extreme scenario.

The other two types of assumptions made in the alternative scenarios are around the extent to which smart capabilities can reduce the probability of fire (relative to non-smart appliances) and the probability of becoming severely injured or dying from fires. These assumptions reflect the effectiveness of smart technology at preventing harm.

Fires arising from component failures, particularly capacitor failures, tend to be spontaneous and very difficult to predict. However, experts suggested up to half of appliance fires could be predicted with condition monitoring and predictive maintenance technology. Whether the fire can then be prevented depends on the intervention required by the manufacturer and the consumer. If the manufacturer is able to shut the machine down remotely, it is likely all

[249] 2023 and 2025 forecasts are taken from the Statista Digital Market Outlook. The forecast for 2030 is estimated in Excel using the Statista data and an exponential smoothing algorithm.
[250] RSM UK (2020), Evidencing the cost of the UK Government’s proposed regulatory interventions for consumer IoT: Technical Report. DCMS.

predicted fires could be prevented, but if the prevention depends on the consumer to act or consent, it is less likely that predicted fires will be prevented. The lead time to failure could also be a dependent factor. With a short lead time to failure (i.e. hours or days), consumers may not have time to contact the manufacturer or an engineer to fix the problem. However, a longer lead time (i.e. months or years) could result in procrastination and the consumer not acting. Hence, assumptions are made about what sort of magnitude of harm reduction with condition monitoring and predictive maintenance we might see.

- In scenario 1, we assume that condition monitoring and predictive maintenance leads to a 16.7% reduction in the probability of fire (relative to a non-smart product). In other words, for every six faulty appliance fires that occur in non-smart appliances, one of these could have been prevented had condition monitoring and predictive maintenance been used.
- In scenario 2, we assume that condition monitoring and predictive maintenance leads to a 33.3% reduction in the likelihood of a fire (relative to non-smart or unconnected appliances). In other words, for every three faulty appliance fires that occur in non-smart appliances, one of these could have been prevented had condition monitoring and predictive maintenance been used.
- In scenario 3, we assume that condition monitoring and predictive maintenance leads to a 50% reduction in the likelihood of a fire (relative to non-smart or unconnected appliances). In other words, for every two faulty appliance fires that occur in non-smart appliances, one of these could have been prevented had condition monitoring and predictive maintenance been used.
- In scenario 4, we assume that the risk of fire is almost fully eliminated by adopting smart technologies (i.e. the probability of a smart appliance causing a faulty appliance fire is almost zero). While this level of effectiveness may be out of reach for current technology, this scenario provides an upper bound to our analysis if future developments were made. The risk of fire is not fully reduced to zero to reflect that not all fires can be foreseen and prevented.

In the fourth scenario, we also add in an additional assumption to reflect the safety benefits of connectivity. We assume that connected homes are more prevalent, therefore consumers have connectivity across devices (e.g. smart speaker and smoke alarm) to warn them of harm. Applying this additional assumption does not change the total number of injuries and fatalities avoided. However, the types of harms avoided differ. To estimate how the distribution of injury types change, we compare the distribution of injuries and fatalities amongst those injured (or fatally injured) for all faulty appliance fires with that for faulty appliance fires where smoke alarms did not operate correctly using the Home Office data on fatalities and casualties in fires in England[251]. In fires where a smoke alarm does not work, the types of injuries that consumers suffer from are typically more severe. Fatalities and injuries requiring hospitalisation are more likely when smoke alarms do not operate, and minor injuries (requiring first aid or a precautionary check) are less common. Therefore, to capture how connectivity can provide the additional benefit of avoiding severe harms in this scenario, the likelihoods of different injury types are adjusted to reflect this. In the first three scenarios, smart take-up is still relatively low. Therefore, we assume that most consumers do not have connectivity to other smart products and the probability of severe injuries and fatalities being caused by a fire are not adjusted.

Table 10 summarises the assumptions made in each modelling scenario.

[251] Home Office Fire Statistics Tables.

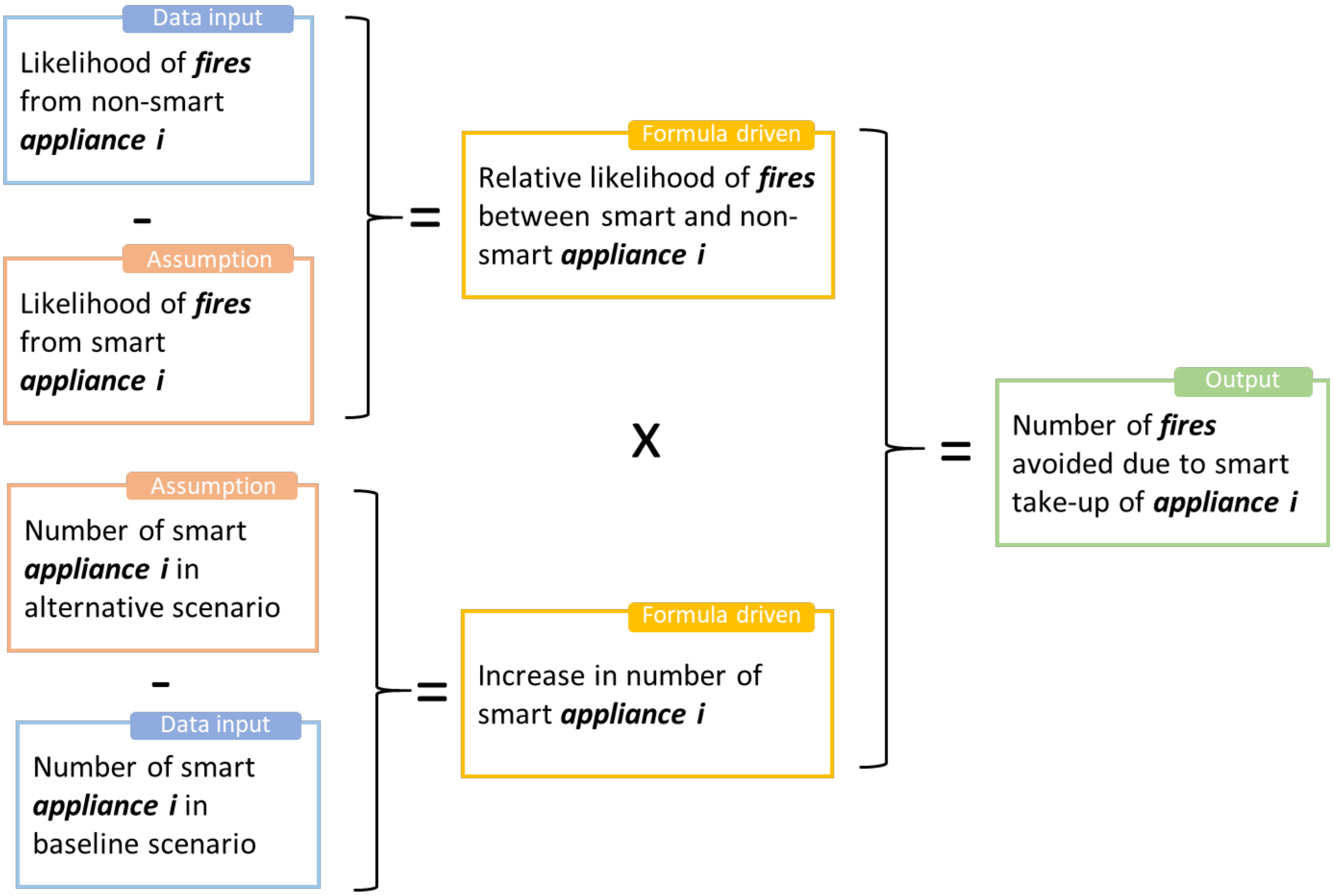
Table 9: Modelling scenarios and assumptions

Scenario	Baseline	Alternative Scenario 1	Alternative Scenario 2	Alternative Scenario 3	Alternative Scenario 4
Proportion of appliances that are smart	3.2%	7.3% (based on 2023 forecasts)	12.9% (based on 2025 forecasts)	28.7% (based on 2030 forecasts)	100.0%
Proportion of smart appliances that are connected	Cookers/ovens: 24% Washing machines, tumble dryers, washer/dryers: 24% Dishwashers: 34% Fridge/freezers: 40%	As per baseline	As per baseline	As per baseline	Cookers/ovens: 77% Washing machines, tumble dryers, washer/dryers: 60% Dishwashers: 76% Fridge/freezers: 79%
Proportion of appliances that have condition monitoring capabilities	See Table 8	As per baseline (see Table 8)	As per baseline (see Table 8)	As per baseline (see Table 8)	100.0% (for all types of appliance)
% reduction in probability of fire by implementing smart technology	n/a	16.7%	33.3%	50.0%	99.0%
Reduction in the probability of severe injuries and fatalities due to connectivity	n/a	No	No	No	Yes

Calculating the number of fires prevented

The modelling approach assumes that condition monitoring and predictive maintenance reduce the probability of fires occurring (relative to non-smart appliances)[252]. As discussed above, how much the probability is reduced by is assumed in the different alternative scenarios. To estimate how many fires this technology could prevent (in expectation) across all appliances, the relative likelihood of fires is multiplied by the increase in the number of smart appliances (with these capabilities) between the alternative and the baseline scenario. This calculation is shown in Figure 6 below.

Figure 6: Calculation approach to estimate the number of fires avoided due to smart take-up



Notes: appliance i refers to the general case. Each of the six appliance types are analysed separately. The likelihood of fires are estimated by dividing the number of fires by appliance i in 2019/20 in England by the number of appliance i in circulation in England in 2019/20.

Calculating the number of avoided harms and prevented costs

Following the estimation of the number of fires avoided, the next step is to quantify and value the avoided fire-related outcomes. The fire related outcomes that are included in the analysis are:

- Injuries (of different levels of severity);
- Fatalities;

[252] In absence of fires data from other UK nations, the probability (or likelihood) of a fire occurring is estimated using English data on the number of faulty appliance fires observed in 2019/20 and the number of appliances in circulation in England. The underlying assumption being that faulty appliance fires are equally as likely in Scotland, Wales and Northern Ireland as in England.

- Property damage (of different levels of severity);
- Use of fire services resources; and,
- Post traumatic stress disorder (PTSD).

Fires data from the Home Office publishes information on the severity of injuries and extent of property damage due to fires. Therefore, the modelling also distinguishes the severities of injuries and property damage that result from fires in the analysis. The severity levels of injuries used are defined as:

- Preventative check: Where a precautionary check (to attend hospital or to see a doctor) was recommended (by anyone).
- First Aid given: Where first aid was given at scene (by anyone), including after a precautionary check.
- Hospital (slight): Where attending hospital as an outpatient (not a precautionary check) is required.
- Hospital (severe): Where at least an overnight stay in hospital as an in-patient is required.

Property damage severity is defined using 10 categories. The categories are based on those recorded in the Home Office data and represent the total horizontal area (in square metres) damaged by the flame and/or heat at the stop of the fire. The categories range from 0 metre squared (i.e. no damage caused) to over 1000 metre squared.

To quantify and monetise these avoided outcomes, we use two types of parameter:

- The likelihood of such outcomes following an LDA fire; and,
- Unit costs of the fire-related outcomes (e.g. the value of lives lost can be quantified using 'value of statistical life approaches')

Since the analysis calculates the number of fires that are avoided which would have otherwise been recorded in the Home Office data (i.e. the fire service would have been called out), the likelihood of using fire service resources is 100% for all appliance fires.

The Home Office fires data is used to estimate the likelihood of property damage, fatalities and injuries in LDA fires. Specifically, the number of each of these specific harms observed in faulty appliance fires in England since 2010 is divided by the total number of faulty appliance fires in England since 2010. Table 11 and Table 12 below summarise the likelihood of each of these harms for the modelled appliances and the total number of fires the estimate of the likelihood is based on.

Estimating the likelihood of PTSD following a fire is more challenging given that psychological illnesses are more complex to understand and trace the causes of. Nevertheless, evidence from the NHS finds that 1 in 3 people suffer from PTSD following a traumatic event[253]. Therefore, we assume that fires in which there was some property damage qualify as a traumatic event and so apply this incidence rate to the proportion of fires that cause any level of damage. The PTSD likelihoods are reported in Table 11.

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[253] NHS: Overview - Post-traumatic stress disorder

Table 10: Estimated likelihoods of property damage (of different severities) and PTSD from a faulty appliance fire (based on faulty appliance fires over 10-year period)

Appliance	$0m^2$	Up to $5m^2$	6 to $10m^2$	11 to $20m^2$	21 to $50m^2$	51 to $100m^2$	101 to $200m^2$	201 to $500m^2$	501 to $1000m^2$	Over $1000m^2$	PTSD	Sample size likelihoods are based on
Cookers/Ovens	27.7%	68.8%	1.9%	1.0%	0.1%	0.4%	0.0%	0.0%	0.0%	0.0%	24.1%	**2,721**
Washing Machines	36.5%	56.6%	3.8%	1.7%	0.3%	1.0%	0.1%	0.0%	0.0%	0.0%	21.2%	**4,774**
Tumble Dryers	21.6%	51.3%	12.4%	8.5%	1.6%	4.1%	0.4%	0.1%	0.1%	0.0%	26.1%	**4,278**
Washer/Dryers	35.1%	58.2%	2.9%	2.5%	0.3%	0.5%	0.0%	0.2%	0.3%	0.0%	21.6%	**593**
Dishwashers	13.9%	66.7%	10.9%	5.3%	0.7%	2.2%	0.3%	0.1%	0.0%	0.0%	28.7%	**2,803**
Fridge/Freezers	10.1%	41.1%	19.9%	14.0%	3.6%	9.2%	1.5%	0.6%	0.0%	0.0%	30.0%	**2,132**

Note: The 10-year period covered is 2010/2011 to 2019/2020.

Table 11: Estimated likelihoods of fatality and injuries (of different severities) from a faulty appliance fire (based on faulty appliance fires over 10-year period)

Appliance	Fatality	Precautionary check	First aid given	Hospital slight	Hospital severe	Sample size likelihoods are based on
Cookers/Ovens	0.1%	3.0%	4.5%	3.5%	0.2%	**5,691**
Washing Machines	0.7%	4.3%	5.7%	5.6%	0.9%	**22,458**
Tumble Dryers	0.7%	4.3%	5.7%	5.6%	0.9%	**22,458**
Washer/Dryers	0.7%	4.3%	5.7%	5.6%	0.9%	**22,458**
Dishwashers	0.7%	4.3%	5.7%	5.6%	0.9%	**22,458**
Fridge/Freezers	0.7%	4.3%	5.7%	5.6%	0.9%	**22,458**

Note: The 10-year period covered is 2010/2011 to 2019/2020. These likelihoods are used for scenario 1, 2, and 3. Likelihoods are slightly adjusted in scenario 4 to reflect the connectivity benefit. Datasets on fatalities and casualties in fires in England (provided by the Home Office) do not provide data at a granular enough level to distinguish fires caused by each of the appliances. Therefore, a broader category of “Cooking appliances” is used for Cooker/Ovens and “Other electrical appliances” is used across all the other appliances modelled. This explains why the estimated likelihoods are the same for washing machines, tumble dryers, washer/dryers, dishwashers and fridge/freezers.

To estimate the total cost of avoided fires, we use the unit costs attributed to the different fire-related outcomes. Table 13 below summarises the values used for each outcome and the source.

Table 12: Unit costs of fire-related outcomes used in the analysis

Avoided outcome	Value attributed	Source	Notes
Fatality	£2,084,404	Department for Transport, Transport Appraisal Guidance, Table A4.1.1.	Includes medical costs (£1,230), human costs[254] (£1,366,627) and lost output (£716,547)
Injury (Precautionary check)	£131	Unit costs of Health and Social Care 2020[255]	Captures the medical costs associated with a precautionary check
Injury (First aid given)	£214	Unit costs of Health and Social Care 2020	Captures the medical costs associated with first aid
Injury (Hospital slight)	£18,057.	Department for Transport, Transport Appraisal Guidance, Table A4.1.1.	Includes medical costs (£1,238), human costs (£13,902) and lost output (£2,918)
Injury (Hospital severe)	£234,229	Department for Transport, Transport Appraisal Guidance, Table A4.1.1.	Includes medical costs (£16,724), human costs (£189,899) and lost output (£27,606)
Damage (0m^2)	£0	-	No damage so attributed zero cost
Damage (Up to 5m^2)	£47,004	Data points from the Building Cost Information Service (BCIS)	Reflects the rebuild cost of a house, where the fixed rebuild cost is £43,895 and the variable rebuild cost per square metre is £1,244[256].

254 Human costs reflect the lost quality of life as a result of the injury/fatality.
255 Curtis and Burns (2020) Unit costs of Health and Social Care 2020.
256 Using the Building Cost Information service, three data points of the rebuild cost for houses in St Austell, Cornwall are reported here. A linear regression of the rebuild cost against the size of these properties estimates that the fixed rebuild cost is £43,895 and the variable rebuild cost per square metre is £1,244. Using these two cost estimates, the rebuild cost associated with each of the severity levels of property damage are calculated.

Damage (6 to 10m^2)	£53,843	BCIS	As above
Damage (11 to 20m^2)	£63,169	BCIS	As above
Damage (21 to 50m^2)	£88,040	BCIS	As above
Damage (51 to 100m^2)	£137,780	BCIS	As above
Damage (101 to 200m^2)	£231,044	BCIS	As above
Damage (201 to 500m^2)	£479,747	BCIS	As above
Damage (501 to 1000m^2)	£977,153	BCIS	As above
Damage (Over 1000m^2)	£1,287,410	BCIS	As above
PTSD	£44,998	Judicial College Guidelines for Personal Compensation[257]	Average of the range of compensation available for PTSD (£3,398 and £86,597)
Resource cost	£4,414	Department for Communities and Local Government[258]	Average of the response cost by region, weighted by the number of faulty appliance fires since 2010 per region.

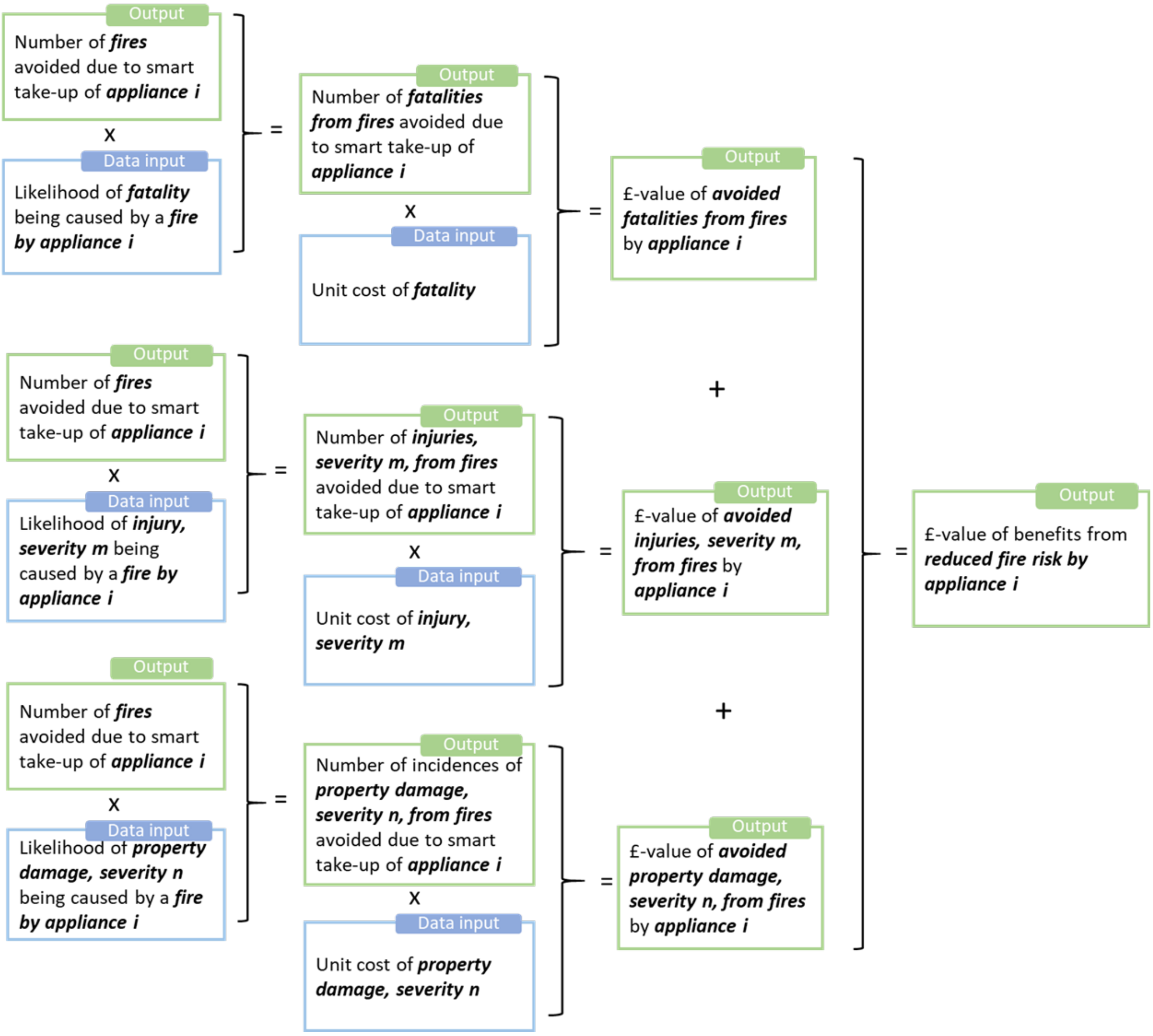
Note: Values are in 2020 prices and rounded to nearest pound.

Returning back to the calculation approach, taking fatalities as an example, to estimate the number of fatalities avoided, the number of fires avoided as a result of smart take-up is multiplied by the likelihood of a fatality from a fire. To estimate the value of these avoided fatalities, the number of fatalities avoided is multiplied by the unit cost of a lost life. Repeating this calculation for all the fire related outcomes and summing across all outcomes gives the total avoided costs from fires. The approach is summarised in Figure 7 below for the valuation of fatalities, injuries (of general severity level ‘*m*’) and property damage (of general severity level ‘*n*’).

[257] The Judicial College Guidelines (15th Edition) – What Has Changed?. Available at: https://www.bc-legal.co.uk/bcdn/1029-297-the-judicial-college-guidelines-15th-edition-what-has-changed.html

[258] Table 22, Department for Communities and Local Government (2011). The economic cost of fire: estimates for 2008. Available at: https://webarchive.nationalarchives.gov.uk/20121105004836/http://www.communities.gov.uk/documents/corporate/pdf/1838338.pdf

Figure 7: Quantifying and valuing injuries, fatalities and property damage from avoided fires



Note: appliance i, injury severity m and property damage n refer to the general case. Each of the six appliance types will be analysed separately.

4.1.2 Findings

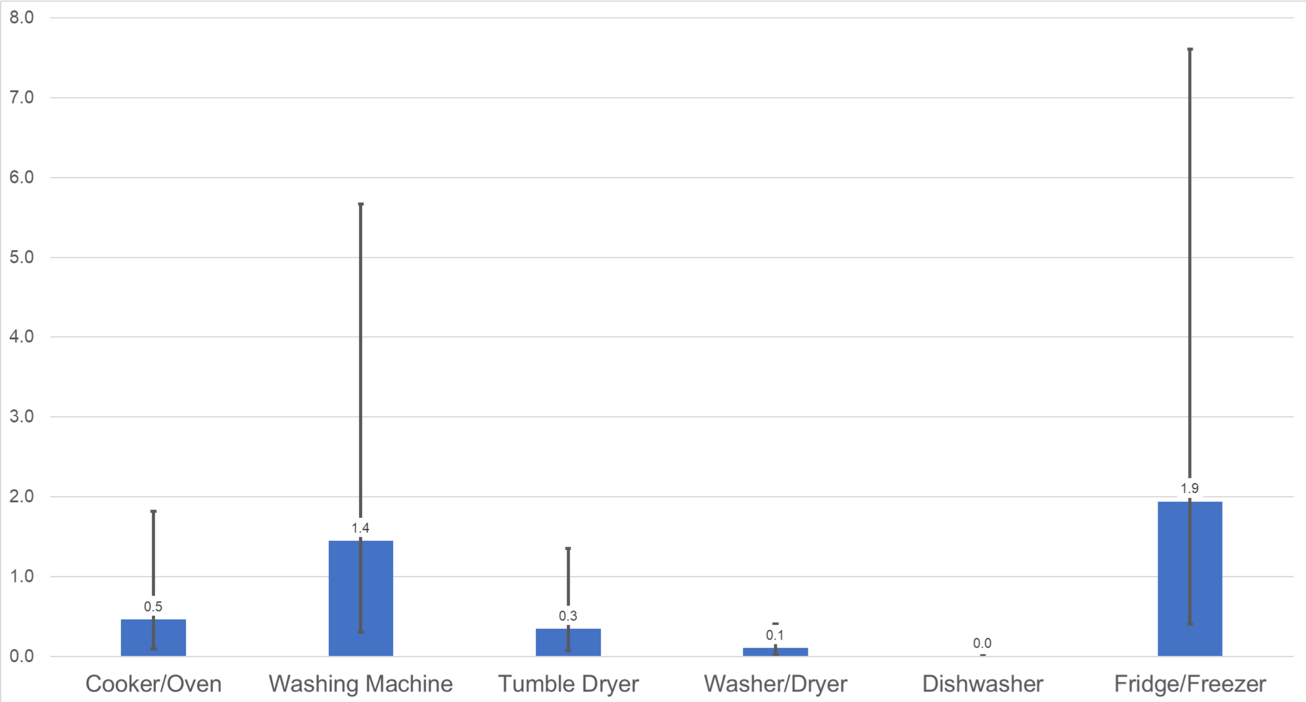
Scenarios 1, 2 and 3

The first three scenarios were developed to simulate realistic impact of smart technology over the near future. Overall, these scenarios demonstrate that smart appliances could lead to fires being avoided each year, albeit the number of fires is relatively small. This corroborates the qualitative findings from this study that the safety benefit of smart appliances is not particularly large relative to other benefits it could bring, such as improved functionality.

Using scenario 2 as the central scenario, the number of avoided fires per year is largest for fridge freezers (1.9, 0.8% reduction) and washing machines (1.4, 0.2% reduction). For fridge freezers, this is primarily driven by the high number of appliances in circulation and relatively high proportion of these appliances being connected. For washing machines, the result is driven by a high number of faulty appliance fires caused by washing machines (in comparison to other appliance types). There is very limited impact of smart technology in dishwashers (almost 0 fires are avoided per year). Since this appliance has the lowest proportion of appliances with condition monitoring, the capacity to reduce fires by adopting smart dishwashers is low.

In total across the appliances, the number of fires avoided per year is around 1 for scenario 1, 4 for scenario 2 and 17 for scenario 3. Figure 7 below shows the number of avoided fires for scenarios 1, 2 and 3 by appliance.

Figure 8: Number of fires avoided per year relative to baseline (Scenario 1,2,3)



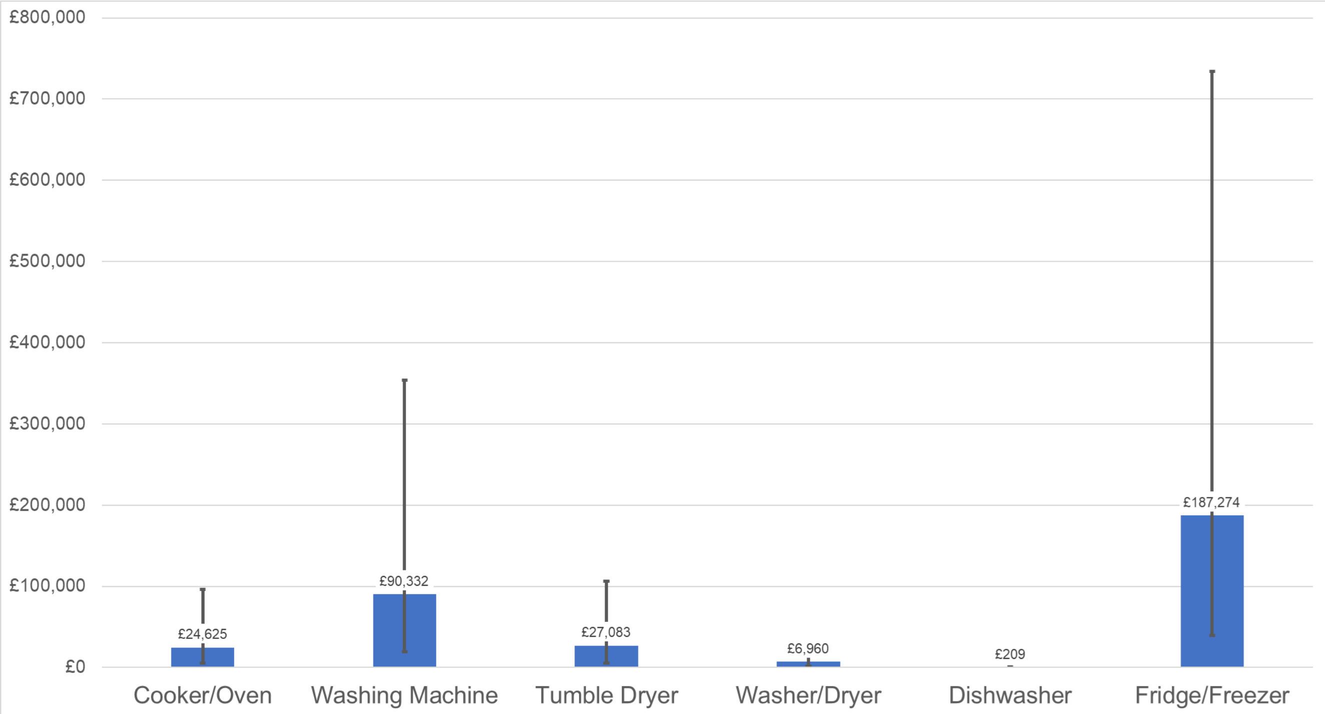
Source: London Economics' analysis. Note: scenario 2 results are shown by the blue bars. Scenario 1 and 3 results are shown by the bottom and top of the range respectively.

Every fire avoided has the potential to save lives, prevent injuries and damage, and reduce costs to the emergency services. Home Office data shows that fatalities and severe injuries are very rare in faulty appliance fires: around 1 in 153 electrical appliance fires involve a fatality and 1 in every 15 electrical appliance fires result in a hospitalised injury. Therefore, since the **number of fires avoided is between 1 and 17 in scenario 1, 2 and 3**, very few injuries and fatalities are avoided.

Consequently, the avoided costs per year are **£71,000 for scenario 1**, **£336,500 for scenario 2 and £1.3 million for scenario 3**. Fridge/freezers contribute the majority of these total costs avoided (56%) and dishwashers contribute the least (0.1%). Since the overall cost avoided is relatively small, the benefits of adopting this technology (i.e. the cost avoided from fires) may not outweigh the cost of implementing this technology and getting consumers to engage with it.

Figure 9 below shows the costs avoided per year. The costs follow a similar pattern to the number of fires avoided.

Figure 9: Costs avoided per year from avoided fires (Scenario 1,2,3)



Source: London Economics' analysis. Note: scenario 2 results are shown by the blue bars. Scenario 1 and 3 results are shown by the bottom and top of the range respectively.

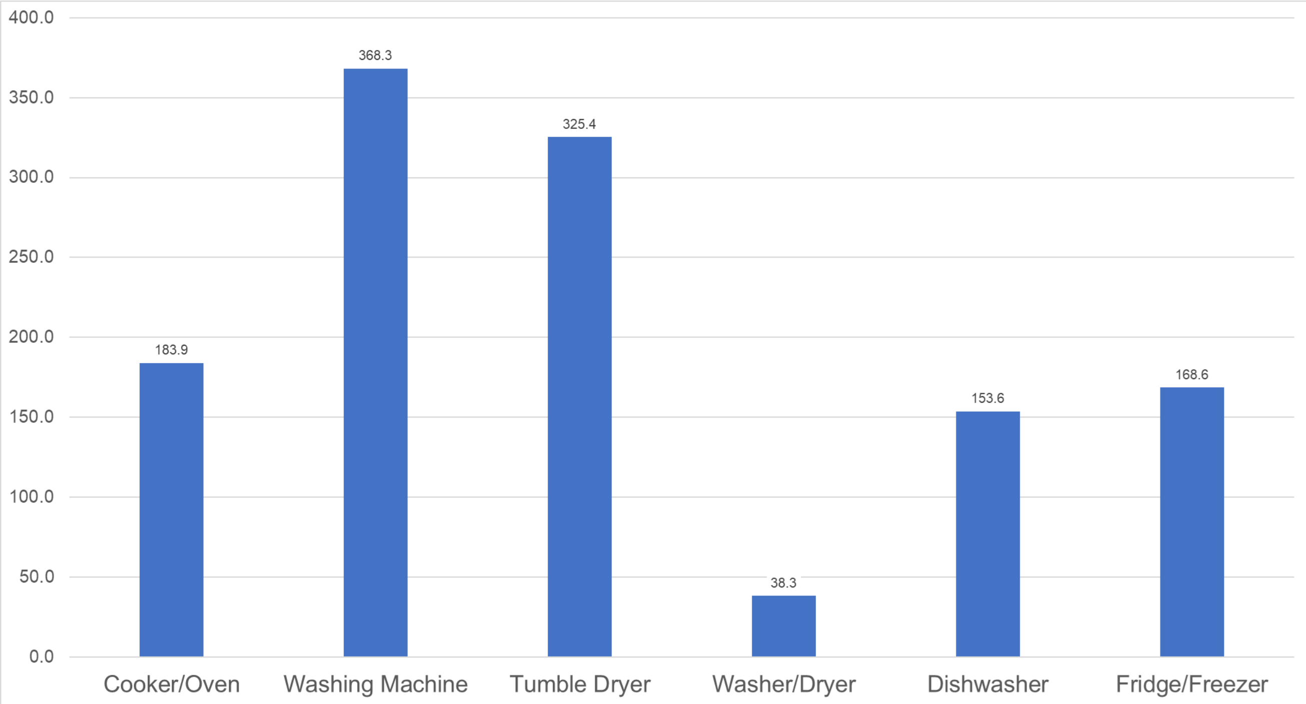
Scenario 4

While the impact for the first three scenarios is fairly small, the fourth modelling scenario is used to demonstrate **upper bound impact** should smart appliances become more widely adopted and technology develops. It is important to note that these results show the full potential of smart technology but **do not** capture the current capabilities of technology available on the market.

Under this scenario the simulated impact is larger. Across the appliance types, **1,238 faulty appliance fires could be avoided per year**. The number of fires avoided varies by appliance types. Washing machines and tumble dryers could have 368 and 325 fires avoided per year, respectively (reductions of 59.3%). This reflects that faulty appliance fires are currently more prevalent in washing machines and tumble dryers than other appliances.

Figure 10 below show the number of fires avoided for scenario 4.

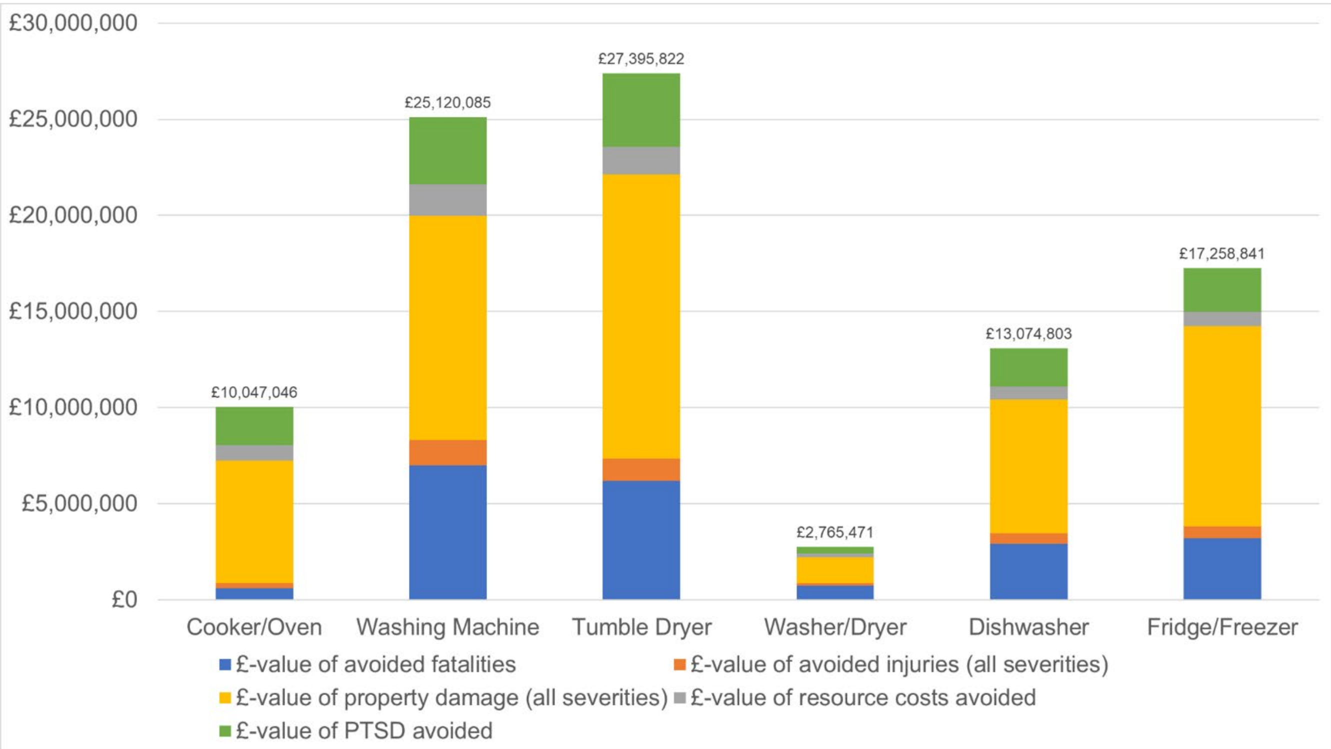
Figure 10: Number of fires avoided per year relative to baseline (Scenario 4)



Source: London Economics' analysis

Across all the appliance types, the total cost that could be avoided is **£95.7 million per year**. The majority of that cost is from avoided property damage (54%), followed by costs associated with avoided fatalities (22%) and avoided PTSD (15%). In terms of avoided harms, 10 fatalities, 191 injuries (75 requiring hospitalisation) and 310 incidences of PTSD could be prevented per year, saving £38.6 million annually in medical costs, lost income and reductions in quality of life.

Figure 11: Costs avoided per year from avoided fires by type of cost (Scenario 4)



Source: London Economics' analysis

The overall cost avoided simulated for scenario 4 (£95.7 million per year) may mean there is sufficient benefits, relative to the costs, to incorporating smart technology into appliances. However, significant developments in technology and both smart technology penetration and use would need to be made for smart appliances to have this magnitude of impact.

4.1.3 Caveats for the modelling

There are caveats to this modelling approach that must be considered, particularly when interpreting its results. These centre around four areas, namely data limitations, modelling scope, comparing smart and non-smart appliances and unintended consequences of smart products related to smart products.

Data limitations

To estimate the number of fires and harms avoided, the analysis primarily relies on Home Office datasets covering domestic appliance fires, fatalities and casualties. Fires avoided are therefore those which would have otherwise been recorded in the Home Office data. There may be minor fires that are not captured in these datasets and consequently are not taken into account in the final results or in the likelihood parameters.

Furthermore, causes of fires recorded in the Home Office data are based on investigations at the scene. There may be some cases where the cause is recorded incorrectly. Before undertaking the analysis, an extensive data review was undertaken to establish relevant data sources and assess the quality of each of the sources found. The London Fire Brigade data is known to have better recording of causes of fires, recording the cause as determined by the post-fire investigation. However, the sample size of this dataset was too small to be able to extrapolate for the whole of the UK. Therefore, it was decided to use the Home Office data instead.

It should also be noted that the Home Office data covers fires in England only. Fire data and statistics are provided by respective authorities in Scotland, Wales and Northern Ireland[259]. However, the data is less granular for these nations. Therefore, we model the total number of fires avoided per year amongst the population of appliances in the UK using English data to estimate the likelihood of fires and the likelihood of the various harms from fires. Implicitly we're assuming that the likelihood of fire and resulting harms in Scotland, Wales, Northern Ireland is equal to the likelihood of fire in England.

Modelling scope

The modelling aims to value the avoided outcomes related to fires. However, there may be other benefits and risks of smart technology that are not included in the analysis.

There are several outcomes from fires that cannot be measured due to limited data. One such example is the property damage that could be prevented as a result of connectivity. This was not able to be modelled because there was no data available showing how levels of property damage change when smoke alarms work or do not work. Furthermore, the unit costs of harm used in the modelling may not capture all the costs incurred to consumers, businesses and government from a fire or medical problem.

[259] Scottish Fire data is available at: https://www.firescotland.gov.uk/about-us/fire-and-rescue-statistics.aspx. Welsh fires data is available at: https://statswales.gov.wales/Catalogue/Community-Safety-and-Social-Inclusion/Community-Safety/Fire-Incidents. Fire statistics for Northern Ireland are provided at: https://www.nifrs.org/home/about-us/statistics/

Furthermore, with improved data collection comes additional risks of data security. While smart appliances could reduce physical harms such as injury, fatalities, and property damage, they also run the risk of security breaches which would result in other types of harms such as emotional distress from disturbed privacy. These types of harms are not included within the modelling approach but are important to consider qualitatively, nevertheless.

Comparing smart and non-smart appliances

The approach compares the likelihood of fire from smart appliance with that of non-smart appliances. This comparison is not necessarily a like for like comparison. There may be other factors that also differ between these two groups of appliances, meaning the analysis may not solely be capturing the effect of introducing smart technology in appliances on the number of fires avoided. For example, smart appliances are more likely to be newer and made to safer design specifications and more developed safety standards so less likely to cause fire.

Unintended consequences of smart products

In the avoided harms analysis, an implicit assumption that is made is that smart appliances decrease the probability of fires relative to non-smart appliances. However, an unintended consequence of smart adoption may be that consumers expose themselves to more risk and become more susceptible to harms. Studies show that consumers do not consider safety when purchasing products and place significant trust in manufacturers.[260] Therefore, smart technology with added safety features might reduce human vigilance or caution around using appliances, which might be harmful. For example, the ability to check on appliances remotely might encourage consumers to run products while they are asleep or away from home, meaning they are not around to supervise the appliance if a problem does arise. The previous OPSS Safety of Smart Domestic Appliance report has carried out a similar modelling exercise to understand how smart products could also increase certain harms, through capabilities like time shifting. This modelling estimated that, with time-shifting, fires at night would increase by 6% (equivalent to 87 per year) by 2030, resulting in an additional 1.1 fatalities.[261] Therefore, to ensure confidence in our modelling assumption that smart appliances decrease the probability of fires relative to non-smart appliances, the analysis includes only fires caused by faulty appliances and assumes condition monitoring and predictive maintenance would indeed reduce the probability of these fires.

4.2 Estimating product recall effectiveness benefits

A second area where our research shows there could be tangible benefits for adopting smart technology is improving product recall effectiveness. Through the stakeholder consultation, we understand that getting consumers to respond to recalls provides a significant challenge for manufacturers. With smart appliances, there is the potential to broaden the options available for manufacturers to improve the recall success rate, including using more direct communication channels to the consumer (via apps or the appliance dashboard). Furthermore, the necessity for consumers to register or connect their smart appliance to benefit from its

[260] BEIS (2020) Consumer Attitudes to product safety. Research Paper Number 2020/032.

[261] In order to offset the 1.1 additional fatalities caused by time shifting, our modelling suggests that a scenario where all smart appliances are connected and at least three quarters of smart appliances have condition monitoring capabilities would be required. Since this statistic relates to the year 2030, the assumed proportion of smart appliances is 28.7% and the assumed percentage reduction in probability of fire by implementing smart technology is 50% (as in Scenario 3).

features means that contact details of consumers are likely to be known to the manufacturer, potentially leading to better targeting and more efficient recalls (see section 2.2).

This analysis examines existing estimates of the recall success rate and estimates the potential uplift that could be observed if manufacturers used strategies that would become more feasible with higher smart take-up.

4.2.1 Recall success rates for non-smart appliances

An important parameter acting as the baseline in this analysis is the current success rate for product recalls. This is used as a best proxy of the recall success rate for non-smart appliances.

Publicly available data on recalls is sparse. However, according to Electrical Safety First, the average success rate of an electrical product recall (i.e. the share of units returned out of the total number in circulation) is just 10-20% in the UK.[262] Research from the US Consumer Product Safety Commission (CPSC) corroborates this, estimating a success rate of 12% for home appliances.[263] These figures are relatively low and may not reflect recalls of LDAs.

In the LDA sector, data from two of Whirlpool's recent recalls shows that around 50% of their recalled tumble dryers have been corrected[264]. In addition, as of March 2021, 196,522[265] (out of 574,500[266]) of Whirlpool's recalled washing machines had been fully resolved, representing a success rate of approximately 33%. Another manufacturer provided us with the following recall effectiveness rates for their recalls. Like Whirlpool's, the recall effectiveness rates are higher relative to the averages found by ESF and CPSC.

Table 13: Recall effectiveness rates from an appliance manufacturer

Product	Production year	Recall start date	% modified
Washing machine	2018	2019	75%
Tumble dryer	2012	2013	89%
Fridge/Freezer	2000-2006	2011	41%
Gas Cookers	2003-2008	2009	57%

Note: % modified refers to the proportion of units to be recalled that are successfully located and modified to remove the risk

4.2.2 Recall success rates for smart appliances

Since smart appliances are relatively nascent in the market, there are limited examples of smart appliances that have been recalled, allowing us to compare the recall success rates directly. Instead, we draw on various sources of evidence (including case studies, a

[262] Electrical Safety First. (2014). Consumer Voices on Product Recall. Electrical Safety First.
[263] US CPSC Recall Effectiveness workshop.
[264] Whirlpool (2019) Whirlpool recall update: tumble dryer owners must come forward
[265] OPSS (2021) Whirlpool washing machine recall update
[266] The number of units to be recalled is published here: https://washingmachinerecall.whirlpool.co.uk/faq.jsp?lang=

behavioural experiment and a consumer survey) to provide an indication of how smart appliances could increase the recall success rate.

Firstly, case studies from outside of the LDA sector, such as the Samsung Galaxy Note 7, demonstrate the potential of smart capabilities for recalls. As discussed above, when discussing the potential benefits of smart technologies relating to recalls, being able to switch products off remotely demonstrates that consumers do not need to be relied upon to act for risks to be removed. Theoretically, recall success could be as high as 100% if the functionality of the device could be reduced to remove risk. Whether in practice this could be implemented and be as successful for larger appliances is questionable. There may be reluctance from consumers, manufacturers and regulators to adopt remote disabling, for reasons including issues around consent, reimbursement and security. A balance must be made weighing up whether this is the best solution given the risk posed by the product.

A study for the European Commission[267] used a behavioural experiment to test the effectiveness of selected remedies on consumers' response to recall notices. The two remedies that were tested were: a general advertisement campaign, which appeared as a banner on a computer screen requiring the consumer to click to find out more information; and, a form of direct communication (where the consumer was directly emailed about the recall of a product they owned). Under direct communication (relative to the general advertisement), the percentage of consumers that returned or disposed of a washing machine under recall increased by 13.8p.p. (from 1.7% to 15.5%). Similar increases were observed for other products (outside of appliances) which were also tested. Adopting smart technology in domestic appliances could have a similar impact on the recall effectiveness rates as observed here. Better traceability can facilitate a direct communication channel between the consumer, retailer and manufacturer should an appliance be recalled and as observed can improve response rates amongst consumers.

Similar uplifts in the recall effectiveness rates when implementing direct notifications (e.g. email, post, telephone) have been found by the US CPSC after analysing 865 closed cases between 2012/13 and 2015/16. They found that a recall notified by a press release, on average, resulted in a 6% response rate, compared to a 50% response rate for a direct recall alert.[268] This represents a 44 percentage point increase in the response rate and, like the results from the behavioural experiment, demonstrates how removing frictions in recall notifications is highly effective at improving return rates.

Previous research by OPSS found that 19% of respondents reported taking no action after seeing a recall or safety warning[269]. However, with more direct communication this proportion could be reduced. Survey results from the second wave of the OPSS consumer survey[270] can elicit an estimate of how likely consumers are to act upon a recall announcement following notification via the product or app. The question asked in the survey was: *How likely would you be to act if a product you owned alerted you via the product/ associated app of issues with the product?,* with consumers responding on a scale of Very Likely, Fairly Likely, Fairly Unlikely and Very unlikely. The results are shown in Figure 12 below.

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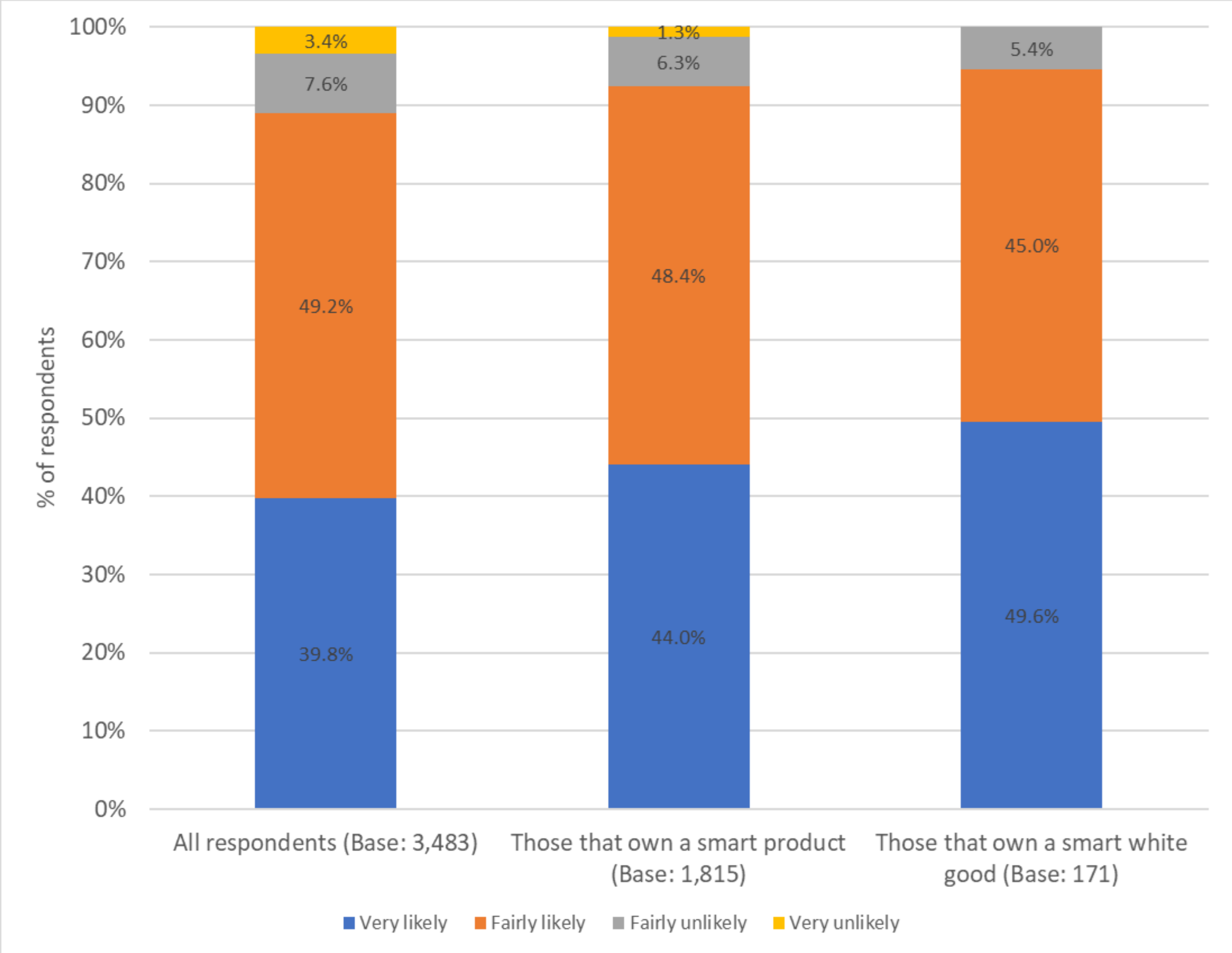
[267] European Commission (2021) Behavioural study on strategies to improve the effectiveness of product recalls
[268] US CPSC Recall Effectiveness workshop.
[269] Figure 10, OPSS (2020) Consumer attitudes to product safety.
[270] OPSS (2022) Product Safety and Consumers: Wave 2

Figure 12: How likely would you be to act if a product you owned alerted you via the product/ associated app of issues with the product?



Source: OPSS Product Safety and Consumers Survey: Wave 2. Note: Of those that expressed an opinion. 'Don't know' responses have been excluded.

The results show that consumers reported they are very willing to return products. Of those that expressed an opinion, 89% of respondents said they would be very likely or fairly likely to act in such a situation, with the remaining 11% of the sample saying they would be unlikely or very unlikely (a reduction from the 19% found previously). The proportion of respondents likely to act increases when the sample is broken down into those that own at least one smart product (of any kind) (92.5%) and those that own a smart white good (94.6%). Differences in the likelihood of acting following a recall notification across these groups of consumers is likely to be driven by their familiarity with smart products. The survey also finds that consumers with smart white goods were generally more comfortable with the idea of a smart product alerting them of a recall notification, collecting data on the product and making remote changes, compared to the sample of respondents as a whole.

By assuming a likelihood of acting for each of the categorical answers ('*very likely*' through to '*very unlikely*') and calculating a weighted average using the distribution of responses given, one can estimate the success rate of recalls for smart products. The estimations are shown in Table 15 with three different assumptions about the possible likelihoods the categorical answers could take.

Table 14: Estimated likelihood of a consumer acting following a direct recall notification

Assumed likelihood of return	All respondents (Base: 3,483)	Those that own a smart product (Base: 1,815)	Those that own a smart white good (Base: 171)
Very likely: 100% Fairly likely: 66.7% Fairly unlikely: 33.3% Very unlikely: 0%	75.1%	78.4%	81.4%
Very likely: 87.5% Fairly likely: 62.5% Fairly unlikely: 37.5% Very unlikely: 12.5%	68.8%	71.3%	73.5%
Very likely: 90% Fairly likely: 65% Fairly unlikely: 35% Very unlikely: 10%	70.8%	73.4%	75.8%
Average return rate	**71.6%**	**74.4%**	**76.9%**

Source: London Economics analysis of the OPSS Product Safety and Consumers: Wave 2

As shown by Table 15, according to the results from the OPSS consumer survey, the recall success rate for smart appliances could be as high as 71-77%. Comparing this with the ESF and CPSC figures of the average success rate for a non-smart appliance, the results indicate a potential improvement in the recall response rate of between 51 and 67 p.p.

4.2.3 Potential uplift in the recall success rate with smart technology

To summarise, we have three main sources evidencing the potential magnitude of an uplift in the recall effectiveness rate from adopting smart technology in appliances. The European Commission provides the lowest estimate of the uplift at 13.8p.p, followed by the CPSC (at 44p.p.). The Attitudes Tracker has the highest estimates of an increase between 60p.p. to 67 p.p. However, in a consumer survey, consumers may overstate their willingness to act. Corroborating these findings with the European Commission behavioural experiment and CPSC evidence provides a more accurate reflection of the propensity of consumers to respond in practice when they may be faced with other distractions around them.

Such improvements in the recall success rate could lead to significant benefits, including more products being returned and modified, as well as the potential for injuries and fatalities to be avoided.

Using the uplifts in recall success rate found in existing evidence, below we provide an indication of the increase in the number of products these uplifts could lead to in typical appliance recall. Of the 182 recalls for electrical appliances and equipment recorded in the EU RAPEX Safety Gate dataset between 2015 and 2020, the mean number of units to be recalled was 98,412[271].[272].

[271] European Commission: RAPEX Safety Gate Dataset

[272] When quantities are notified to RAPEX, the numbers might be incomplete and grow over time when follow-up reactions come in, hence these available figures are likely to be an underestimation.

In a recall of this size for smart appliances with a wifi connection, we assume 28.3% of these would be connected[273] (approximately 27,822) enabling direct communication and better traceability. Therefore, the estimated uplift in the number of units returned is between 3,839 and 18,641 (see Table 16).

Table 15: Impact of the potential uplift in recall effectiveness rate with wifi connection

Source	Potential uplift in recall effectiveness rate	Number of connected appliances in the recall (assume 28.3% are connected)	Uplift in number of units returned in an average electrical appliance recall
European Commission study	13.8p.p.	27,822	3,839 (3.9% increase)
US CPSC recall effectiveness research	44p.p.	27,822	12,242 (12.4% increase)
OPSS Public Attitude Tracker	51 to 67p.p.	27,822	14,189 to 18,641 (14.4% to 19.0% increase)

If all appliances were connected through a mobile network connection meaning automatic connection, the impact would be greater since all recalled appliances could be traced. Our analysis suggests that the estimated uplift in the number of units returned is between 13,581 to 65,936 (see Table 17).

Table 16: Impact of the potential uplift in recall effectiveness rate with mobile network connection

Source	Potential uplift in recall effectiveness rate	Number of connected appliances in the recall	Uplift in number of units returned in an average electrical appliance recall
European Commission study	13.8p.p.	98,412	13,581 (13.8% increase)
US CPSC recall effectiveness research	44p.p.	98,412	43,301 (44% increase)
OPSS Public Attitude Tracker	51 to 67p.p.	98,412	50,190 to 65,936 (51% to 67% increase)

[273] Average connection rate reported by consumers across Oven, Cooker, Fridge/Freezer, Dishwasher, Washer/Dryer. Table 22: RSM UK (2020), Evidencing the cost of the UK Government’s proposed regulatory interventions for consumer IoT: Technical Report.

5 Conclusions

The evidence collected during this study suggests that connected technologies have the potential to bring a range of safety benefits to LDAs, but there are a number of limitations and barriers to adoptions to consider. Furthermore, while adoption of connected technologies can help to improve safety, the value of harm avoided by connected technology adoption may be relatively modest.

5.1 Key areas of potential safety benefits from connected technology adoption

5.1.1 Condition monitoring and predictive maintenance

Condition monitoring, and the integration of smart technology into condition monitoring, is increasingly used in industrial settings, with condition monitoring experts noting that this technology is already used widely in industrial equipment and plant production. The key motivation for implementing condition monitoring in industry appears to be focussed more on functionality and reducing downtime rather than improving safety. However, the evidence does not suggest that condition monitoring has yet been implemented on a large scale in large domestic appliances (LDAs).

The literature and consultations with stakeholders have suggested there could be potential safety benefits including:

- Condition monitoring to detect potential failures relating to variables such as appliance vibration, temperature, pressure or moisture;
- Predictive maintenance to identify and flag faults to consumers or manufacturers before they develop into safety hazards;
- Improving the efficiency of repairs by helping to better identify the particular problem with the appliance and the parts that may be required to repair it; and
- Enhanced ability to identify the products that were the sources of safety incidents such as fires.

There are also functionality benefits for consumers, for example increasing the longevity of their appliance and accessing quicker and more efficient repairs.

However, there are also several challenges and limitations which could hinder the uptake of condition monitoring technology in LDAs. These limitations largely centre around the cost, practicality and effectiveness of installing sensors in an appliance to detect signs of early failures relative to other solutions. The uncertainty around how many sensors will be required for each appliance, how effective they will be to prevent failures and safety hazards, and the cost of installation may lead manufacturers to pursue other solutions to prevent safety hazards such as containment of components in fire-resistant casing. In addition, new risk factors may be introduced such as the storage and processing of the large amounts of data generated by connected technologies and condition monitoring.

Moreover, while lower costs and greater commoditisation of IoT components, chips and sensors may incentivise adoption, there may be a risk that these safety benefits are only implemented for more expensive, or 'premium' products.

5.1.2 Improving the effectiveness of product recalls

Product recalls are an important form of corrective action to remove unsafe or non-compliant products from consumers' hands. Evidence gathered during this study suggests that connected technologies can both reduce the need for a product recall and improve efficiency and safety during a recall, through channels including:

- Remote repairs implemented through mechanisms such as software updates;
- Improved communication e.g. up-to-date information during a product recall, or conveying maintenance and safety information;
- Improved ability to 'track and trace' consumers who possess products that are impacted by a recall. Existing research and interviewed stakeholders indicated that IoT technologies can help manufacturers to more easily track and trace products and identify those with possible defects at any point in the supply chain[274][275]. Many stakeholders pointed out that sectors with more effective recalls (e.g. automotive) also have better traceability.
- Connected technologies may also enable remote disabling of unsafe appliances, which would prevent consumer exposure to the safety risk because of the fault in the appliance. However, stakeholders highlighted that there might be consumer protection issues if such remote disabling infringed on consumers' rights, or even lead to unintended adverse safety consequences e.g. disabling refrigerators used to store medication.

5.1.3 Other safety benefits

The research conducted for this study suggested there is scope for other potential safety benefits from connected technologies, including:

- Using consumer experience data to perform safety-enhancing software updates;
- Future design improved through data collected on appliance performance and usage;
- Communication with consumers to encourage appropriate usage;
- Greater longevity through early detection of faults or communicating with consumers about appropriate usage and maintenance of their appliance;
- Preventing accidents in the home and facilitative preventative care for consumers in situations of vulnerability

[274] OECD (2019) Challenges to consumer policy in the digital age: Background report. In: G20 International Conference on Consumer Policy, Tokushima 5-6 September 2019. Paris: OECD Publishing, 1-53.
[275] OECD (2018), "Consumer product safety in the Internet of Things", OECD Digital Economy Papers, No. 267, OECD Publishing, Paris.

5.2 Drivers and barriers to adoption/implementation of smart technologies

The adoption or implementation of smart technologies to enhance safety in LDAs has a number of decision-making considerations, including:

- Consumer appetite for the safety aspects of smart LDAs: evidence suggests that selling-points for consumers tend to be in the areas of functionality, energy-efficiency, or convenience, rather than safety. Indeed, many stakeholders pointed out that manufacturers may find it difficult to find a 'hook' to sell the safety benefits of smart LDAs to consumers. Moreover, stakeholders pointed out that even consumers who purchased smart LDAs frequently did not connect them.

- A range of standards and regulations protect the interests and safety of consumers of LDAs, and are key elements of the decision to adopt or implement smart LDAs. For example, one key challenge in the IoT industry is ensuring adequate regulation to protect consumer safety, without stifling innovation. A frequently expressed concern among stakeholders was that standards-setting and regulation needed to keep pace with technological innovation, which may be challenging. Moreover, some representatives of manufacturers pointed out that inter-regional differences in standards and regulations might place operators in more heavily regulated regions at a competitive disadvantage compared to others. In addition, several stakeholders highlighted the importance of a clear standardised definition of what constitutes 'smart' or 'connected' appliances.

- Moreover, cyber security and data privacy concerns can limit consumer demand for connected technologies. A consumer organisation advised that greater connectivity also increases vulnerability to hacking and other cyber-security risks. However, several stakeholders pointed out that there should not be a significant barrier posed by data protection regulations and privacy concerns, so long as manufacturers are transparent regarding the data they collect and seek the appropriate permissions from consumers.

- Stakeholders highlighted a range of technological barriers that limit the adoption or implementation of connected technologies for LDAs. One key barrier is interoperability, or the ability for different systems to 'talk' to each other. A product safety expert suggested that connected technologies require systems to be integrated across product brands, otherwise the data collected may not be compatible and therefore its value will be limited. Stakeholders pointed out that another barrier to smart LDA adoption is the requirement for reliable fast WiFi connections, which in turn may lead to inequalities between regions or consumer groups; for example, older consumers.

- In general, manufacturer representatives indicated that the costs of integrating smart technologies into LDAs could be considerable, and included the costs of monitoring and processing the large volumes of data collected from such appliances. Such costs would be taken into account and integrating connected technologies into LDAs would typically be done when it was cost-effective to do so. Several stakeholders raised the concern that these costs may be passed on to consumers.

- The reliance on digital access and capability runs the risk of 'leaving behind' certain consumer groups. Concerns about digital security and privacy may be amplified for consumers in circumstances that make them vulnerable and less able to advocate for themselves.

5.3 Value of harm avoided through adoption and implementation of connected technologies in LDAs

The modelling exercise, which focussed on the safety benefits from condition monitoring and predictive maintenance, found that the value of harm avoided through connected technology adoption in the UK is relatively modest: between **1 and 17 fires** would be avoided per year (reduction of 0.05-0.8%), and **between £71,000 and £1.3 million** in avoided costs per year. This corroborates the qualitative findings from this study that the safety benefit of smart appliances is not particularly large relative to other benefits it could bring, such as improved functionality. This is because fatalities and severe injuries are generally low in faulty appliance fires, meaning it is unlikely that the small number of avoided fires modelled would reduce incidents of harm: around 1 in 153 electrical appliance fires involve a fatality and 1 in every 15 electrical appliance fires result in a hospitalised injury[276]. This was limited by estimates for the effectiveness and adoption of current condition monitoring technology alongside current trends in penetration and connection rates of connected appliances. A final, 'extreme' scenario where these limitations were overcome was also modelled, showing the potential for smart technologies to enhance safety of LDAs. However, as pointed out by many stakeholders, human behaviour is also an important driver of the incidence and severity of fires. Therefore, while connected technologies can indeed help to reduce harms from fires, they cannot entirely eliminate fires.

5.4 Impact of smart technology adoption on uplift of recalls effectiveness

The modelling conducted by the study team found that **connected technologies could result in up to 19,000 more recalled LDA units being returned per 100,000 products** (an increase of 19%). This highlights the potential positive impact connected technologies could have on consumer safety, particularly in terms of recalls. This figure assumes that slightly over two-fifths of appliances are connected, however, pushing the proportion of connected appliances further to 100% (considering the use of a mobile connection, for example) results in an increase of up to 66%.

5.5 Concluding remarks

The evidence collected during this study suggests that while connected technologies have the potential to bring a range of safety benefits to LDAs, there are a number of limitations and barriers to adoption to consider. Furthermore, while adoption of connected technologies can help to improve safety, the value of the harm avoided by connected technology adoption, in particular with condition monitoring, may be relatively modest considering current trends in adoption, connection rates and limited evidence on the effectiveness of condition monitoring in LDAs. In contrast, modelling suggests that there is clear potential for connected technologies to positively impact the effectiveness of recalls and hence consumer safety. Additionally, if there is a greater widespread adoption of connected appliances incorporating condition monitoring, alongside a greater percentage of these appliances being connected, it is more likely that the safety benefits of smart appliances could be realised as seen in the 'extreme' example modelled.

[276] Home Office (2020) Detailed analysis of fires attended by fire and rescue services, England, April 2019 to March 2020.

6 Appendix

6.1 Methodology of stakeholder interviews

The study team employed the following approach to conduct stakeholder interviews:

- Determining gaps in the literature that could be plugged by interviews with relevant stakeholders and experts;
- Identifying relevant stakeholder organisations, in discussion with OPSS;
- Identifying relevant individuals within stakeholder organisations. First, the team consulted OPSS and their past experience, and then plugged in gaps using web-searches and subscription services to identify appropriate individuals;
- Drafting and refining the interview topic guide (detailed below) in discussion with OPSS;
- Make initial contact with stakeholders, using a signed letter of introduction from OPSS introducing the study and LE as the contractors, on OPSS letterhead.
- Set up interviews
- After the first 3 – 5 interviews are conducted, conducting a brief teleconference with OPSS to refine the topic guide.
- Taking notes during the interview with interviewee permission and, where necessary, clarifying or following up on specific points with the interviewee

6.1.1 Stakeholder interview topic guide

Study and team introduction

London Economics have been commissioned by the Office of Product Safety Standards (OPSS) to research the benefits of smart domestic appliances. The study follows on from previous research for OPSS on the risks and opportunities of smart large domestic appliances (LDAs) and focuses on 5 products in particular: cookers, washing machines, tumble driers, dish washers and fridge/freezers. Faulty domestic appliances pose safety risks (causing up to 60 fires a week) and AI/IoT can improve the safety of these appliances, by monitoring conditions, improve service designs and running software updates etc. The aim of this work is to identify opportunities to enhance the safety of domestic appliances using smart technology and review the potential drivers and challenges to industry adoption. Our findings will expand the knowledge in this area and help inform any regulatory, policy or operational changes OPSS could make to benefit from emerging smart technology in appliances, as well as help OPSS consider how to use and support this technology to make products safer.

As part of the study, we are consulting with experts such as yourself and other [insert stakeholder type], as well as [delete as appropriate] appliance manufacturers, first responders and product safety experts, regulatory bodies.

Ask interviewee if they have any questions about the study?

Table 17: Stakeholder topic guide questions mapped to interviewee types

Question/Discussion point	Appliance Manufacturer	First Responders	Product Safety Experts	Condition monitoring experts	Trade bodies	Consumer Organisations	Standards/ regulatory bodies
1. Condition monitoring (In case expert has not heard of the specific term before, defined as the process of monitoring a parameter of condition in machinery (vibration, temperature etc.), in order to identify a significant change which is indicative of a developing fault.)							
What are the common safety issues/faults in domestic appliances? Could these be monitored and flagged for maintenance before the fault develops into a potential safety hazard?		X	X	X	X	X	
How could condition monitoring be implemented by LDA manufacturers to identify safety issues? Prompt if respondent is stuck: for example, overheating, increase current draw, gauge pressure etc.	X	X		X			
How effective would condition monitoring be at mitigating the risk of unsafe product failure and preventing harm to consumers?	X	X		X	X		

Reduction in the probability of severe injuries and fatalities due to connectivity	n/a	No	No	No	Yes		
2. More effective data collection and enhanced safety							
What is the potential for smart appliances to collect data such as diagnostics from sensors and service history?	X			X			
How could improved data be used to enhance safety? Prompt if respondent is stuck: (for example, to inform software updates, improve future designs or identify the cause of a fault)?	X	X	X	X	X	X	X
Does improved/increased data collection pose any issues in relation to data privacy? Probe: could this act as a barrier for adoption?	X				X	X	X
Will smart capability be implemented by manufacturers to encourage consumers to initiate product maintenance, either by themselves or via a technician (for example, product service or filter clean)?	X				X		
Could smart capability lead to improved relaying of safety information such as product recalls announcements and	X	X	X		X	X	X

updates on safety instructions and maintenance requirements?							
Could smart capability enable more effective identification of products that were the cause of incidents?	X	X	X		X		X
3. Other benefits of smart appliances							
Can you think of any other benefits/capabilities of smart appliances (relative to unconnected appliances) that could improve safety?	X	X	X		X	X	X
Are there any additional benefits of connectivity? (for example, LDAs connecting to smoke alarms or a smart speaker within the household)	X	X	X		X	X	X
4. Barriers and drivers of adoption and implementation							
Are any of the smart capabilities we've discussed already being implemented or considered in the market?	X			X	X		X
What is the consumer appetite for smart products, specifically smart appliances?	X				X	X	
Are there any other barriers to implementation of smart	X			X	X		

capabilities? Probe: these might include technological barriers e.g. does introducing smart capability reduce the life of the appliance?; or data privacy issues e.g. does GDPR limit what kind of data can be stored, processed or used? Do consumers need to opt in to share this information? Do manufacturers have limitations in their ability to disable/disconnect devices remotely?							
Are there any standards or regulations in place, in relation to smart appliances or smart technologies more generally? (Collect information on applicable standards)	X		X		X	X	X
What other steps could standards makers, regulators and manufacturers take to ensure connectivity and smart technologies enhance the safety of LDAs? Probe: do further steps need to be taken to ensure balance between innovative applications of smart technologies and data privacy? What other steps could standards makers, regulators and manufacturers take to ensure connectivity and smart technologies enhance the	X		X		X	X	X

safety of LDAs? Probe: do further steps need to be taken to ensure balance between innovative applications of smart technologies and data privacy? Probe: is there a common definition/understanding of what constitutes ‘connected/smart appliances’ within standards/regulations?							
Are smart capabilities and their impact on safety being considered in product risk assessments? Are there any estimates of the reduction in risk/likelihood of harm due to smart products?	X	X	X				X
Are there any estimates of how many injuries/fatalities could be avoided if smart appliances were adopted?	X	X	X				X
Could you point us to any information about the type or the severity of harm caused by LDAs, or how these might change if smart technologies were adopted?		X	X				X
Are there any estimates of how many incidents of property damage could be avoided by using smart appliances?	X	X	X				X
5. Learning from other sectors							

Could you point us to any information about the type or the severity of harm caused by LDAs, or how these might change if smart technologies were adopted?		X	X				X
Are there any estimates of how many incidents of property damage could be avoided by using smart appliances?	X	X	X				X

6.1.2 Stakeholder types interviewed

The study team interviewed representatives from product safety experts, trade bodies, consumer organisations, first responders and appliance manufacturers, summarised below.

Table 18: Stakeholder engagement conducted

Stakeholder organisation type	Interviews conducted
Consumer organisations	2
First responders	2
Appliance manufacturers	4
Product safety experts	3
Standards/regulatory bodies	2
Trade bodies	3
Condition Monitoring experts	2

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