Living without electricity

One city’s experience of coping with loss of power

ROYAL ACADEMY OF ENGINEERING

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Inside front cover: Lancaster and the area affected by the flood. Courtesy of Ordnance Survey

Below: the River Lune in normal conditions

Foreword

For more than half a century Britain has had a reliable electricity supply: we have been able to plan our lives on the assumption that there will always be electricity available at the wall socket. Occasionally communities suffer from a power cut but the cause is usually self-evident and local – a branch has fallen across a power line, a contractor has cut through a cable, a fuse has blown in the substation or there has been a fire in a cable duct. The outage affects up to a few hundred properties and the local network operator usually re-establishes a supply within a day.

Because electricity is always there, we have come to rely on it without question and have allowed it to infiltrate all aspects of our lives. The gas central heating in our houses relies on electrical controls and circulating pumps; our cordless phones, computers, Wi-Fi routers and some door locks all need a mains supply. And increasingly we have migrated the way we live from paper to electronic systems – we pay for a coffee with a contactless card, read our bank statement online, keep our address book in 'the cloud' and send emails rather than letters.

In December 2015, life for more than 100,000 people in Lancaster reverted to a pre-electronics era. A flood at an electricity substation resulted in a blackout over the entire city that lasted for more than 24 hours. Suddenly people realised that, without electricity, there is no internet, no mobile phones, no contactless payment, no lifts and no petrol pumps. Although these dependencies were not difficult to see, few had thought through the implications of losing so many aspects of modern life at once.

Three months after the event, Lancaster University brought together representatives from local organisations with policy makers and power system specialists. The conclusions of the workshop are summarised in this report. The failure of the power supply in Lancaster was an important reminder that things will occasionally go wrong and we must learn the lessons from such events.

Sir Mark Walport
Chief Scientific Adviser to HM Government

Summary

AT 10.45PM ON SATURDAY, 5 DECEMBER, ELECTRICITY SUPPLIES TO 61,000 PROPERTIES IN THE CITY WERE CUT

Over the first weekend in December 2015, Storm Desmond brought unprecedented flooding to North Lancashire and Cumbria, including to parts of central Lancaster. At 10.45pm on Saturday, 5 December, electricity supplies to 61,000 properties in the city were cut. Electricity was progressively restored from 4.30am on Monday but was cut again to most areas at 4pm that evening. 75 large diesel generators were brought into the city and connected to local substations which allowed restoration of supplies over the next few days. By Friday, 11 December, the situation was back to normal.

A workshop was held at Lancaster University on 9 March 2016 bringing together researchers, civil society, business and government. Representatives from 16 bodies affected by the loss of supply, 10 civil servants from different government departments, representatives of research organisations and professional engineering bodies, the police, and members of Lancaster University discussed the impact of the loss of supply on other systems and the community. This report is informed by these discussions, supplemented by additional information provided by the participants and others affected by the loss of electricity. It groups what was said into themes, rather than by speaker.

Vulnerability of other systems

The loss of power quickly affected many other services that people take for granted. Most mobile phone coverage was lost within an hour; although most landline phone services were available, many people who had replaced their traditional handsets with cordless phones were unable to connect.

The internet was lost over most of Lancaster and, even where it was available in the street, electricity was not available to supply domestic routers and Wi-Fi hubs. Electronic payment systems were unavailable and most ATM machines did not work. The local TV booster station lost power, which also affected digital radio (DAB) services.

Households, businesses and transport

The immediate effects on households were loss of lighting and electrical appliances. Most homes in the affected area have gas-fired central heating with the control system and circulating pump reliant on electricity, so had no heating. Many homes have all-electric cooking and thus were unable to heat food. There are few high-rise buildings in the city but all lost power for their lifts and some upper floors lost water supplies. After 30 hours


Figure 1: Listening to a speaker from the homeless shelter

without electricity, many households had to throw away at least some of the contents of their freezers.

Many shops near the river were unable to open on Sunday because of the floods. Those that were not affected by the floods were often unable to operate due to lack of light, non-functioning freezers and chillers and lack of electronic tills or card payment systems. Many of those that were open either were providing essentials for free or, if they had back-up power, had long queues of customers paying by cash.

The railway line through Lancaster is powered by feeders near Garstang and Kendal, both well outside the area affected by power cuts. However, even though trains could operate normally, the station was closed at 4pm for safety reasons as there was no platform lighting. Some bus services, many of which start in Morecambe and cross the river to Lancaster, were cancelled because the bridges had been struck by flotsam and could not be inspected. No traffic lights were working and garages could not sell petrol or diesel as pumps are driven by electricity.

Impact on the community

The biggest impact on most people was that few knew what was happening. By looking out of the window, it was obvious that there was a widespread power cut but none of the usual sources of information – TV, internet, text messages or social media – was working. Although there was FM radio coverage, many people did not have a suitable battery-powered radio and reporters in the area had serious difficulties in communicating with their studios.

Vulnerable groups, including those relying on electrically-powered medical appliances and residents of care homes, were more seriously affected.

Reasons for the loss of supply

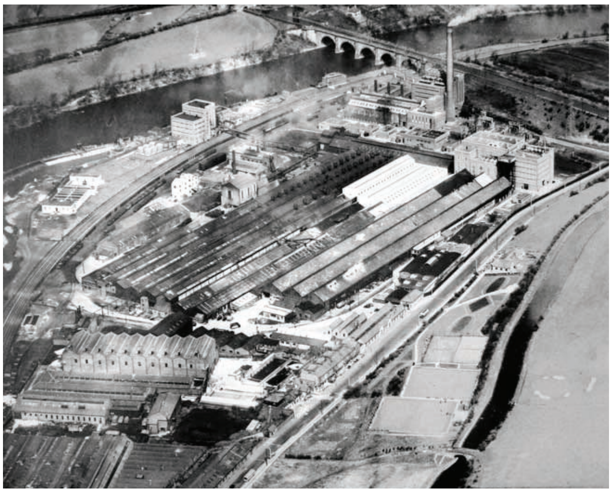

Figure 2: Lancaster power station in the 1950s. (photo: courtesy of Lancaster Museum)

ON 5 DECEMBER, THE MET OFFICE ISSUED A RED SEVERE WEATHER WARNING FOR RAIN IN CUMBRIA AND NORTH LANCASHIRE WITH 150 TO 200 MM EXPECTED IN SOME PLACES

History of the site

The land between Caton Road and the river has been used for industry for many years, originally using water power and, in the 19th century, steam power. In 1865, the Lancaster Railway Carriage and Wagon Company moved into a factory on this site. By the start of World War I, the wagon works had been closed and the site was taken over for the National Projectile Factory which included a power station near the Lune Aqueduct where the canal crosses the river (shown on the map inside the front cover).

When the armaments factory was closed in 1922, Lancaster Corporation took over the power station to supply electricity to Lancaster and Morecambe. Every sizeable town was 'electrifying' and, by the mid-1920s, there were more than 600 local electricity networks, each supplied by its own coal-fired power station. In 1926, the Electricity (Supply) Act set up the Central Electricity Board which started connecting them together with a 132 kV grid. By the outbreak of the World War II, the grid was operating as a national system with nine million consumers.

The photo in figure 2 from the 1950s shows the power station with a tall chimney. By that time, most houses would have been connected to the electricity network via high voltage cables from the Caton Road site and a network of smaller substations around all areas of Lancaster.

Between 1950 and 1975, national electricity consumption quadrupled and hundreds of small local power stations were replaced by fewer large stations. When Lancaster's power station was demolished in the mid-1970s, all the high voltage cables to different parts of the city still came together at the adjacent Caton Road substation so this was where the city remained connected to the national grid. The last major flood, commemorated by a marker on the other side of the river 1.5 metres above the present water level, had been 50 years previously and, presumably, flooding was not seen as a significant risk.

The main substation now consists of three 90 MVA 132/33 kV grid transformers, fed by separate lines, that provide power to the local area. This, in turn, feeds several other substations where the voltage is reduced to 11 kV and then on to a third level of substation where is it reduced further to 415/230 V for domestic and light commercial supplies.

Figure 3: Marker for 1907 flood

AT PEAK, THE ENVIRONMENT AGENCY RECORDED A FLOW OF 1,742 CUBIC METRES OF WATER PER SECOND – THE HIGHEST FLOW OF ANY RIVER EVER RECORDED IN ENGLAND

What happened during the floods

On 5 December, the Met Office issued a red severe weather warning for rain in Cumbria and North Lancashire with 150 to 200 mm expected in some places. There had already been exceptional rainfall in Cumbria in the previous month; much of the ground was already waterlogged and the flood plain upstream of Lancaster was flooded. The River Lune, which runs past the Lancaster main electricity substation, rises to the north of the Howgill Fells in Cumbria and collects water from part of the area covered by the red warning. At peak, the Environment Agency recorded a flow of 1,742 cubic metres of water per second – the highest flow of any river ever recorded in England.

After flooding in recent years, the main Lancaster substation had been provided with a new flood barrier. For most of Saturday 5 December, the water level remained below the top of the barrier but, in the evening, it rose significantly and threatened to flood the substation. High-capacity pumps and additional protection were brought in but were unsuccessful. On-site representatives of Electricity North West (ENWL), the police and the fire service took the decision that, unless the substation was isolated, there was a risk of major damage and, at 10.39pm, the substation was switched off. Supplies were lost to 60,987 consumers.

75 large generators were brought into Lancaster from as far away as the West Country and Northern Ireland and were hooked up to local substations. These allowed 22,000 consumers to be reconnected during Sunday. By noon, the water had receded and the main substation

Figure 4: Sandbags at Lancaster substation (photo: courtesy of Electricity North West)

Figure 5: Generator in Lancaster, connected to local substation

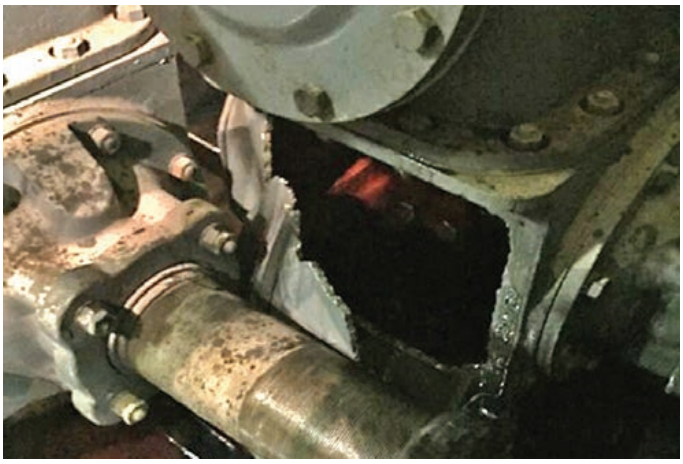

Figure 6: Busbar chamber, showing fault damage (photo: courtesy of Electricity North West)

Figure 7: New cable arriving at substation (photo: courtesy of Electricity North West)

Figure 8: Laying high-voltage cables outside the substation (photo: courtesy of Electricity North West)

had been pumped out, allowing safe access. Grid Transformer 1 was restored at 4.28am on Monday 7 December, which allowed supplies to almost all consumers by 3.30pm.

The arrangement of the main substation is that the three independent 132 kV lines come into three grid transformers which feed a common 33 kV busbar (a connecting point between conductors) and supplies are taken from this busbar to all parts of the neighbourhood. The point where everything comes together is the 33 kV busbar. At 3.56pm on Monday, there was a fault on part of this busbar, due to previous water ingress, resulting in catastrophic failure of the busbar and its enclosure. Figure 6 shows the rupture damage to one end of the busbar chamber.

It was decided that the busbar chamber was unrepairable and, in an impressively short time, the power supply was reconfigured so that Grid Transformer 1 fed the Spring Garden Street and Burrow Beck substations as well as central Lancaster, while the other two transformers provided a duplicated feed to other areas.

This was a major undertaking in difficult conditions, requiring reconnecting much of the substation, but it allowed supplies to be restored progressively over the following day. Restoration was largely completed by 7.18pm on Tuesday 8 December – a remarkably rapid engineering achievement.

RESTORATION WAS LARGELY COMPLETED BY 7.18PM ON TUESDAY 8 DECEMBER – A REMARKABLY RAPID ENGINEERING ACHIEVEMENT

Communications

Telephones and the internet

The wired telephone system, powered from batteries in the exchange, continued to operate over most of Lancaster. Some areas were out of action but that was largely caused by flood water saturating the connection boxes, rather than the loss of electricity supply. Many people who had replaced wired handsets with wireless discovered that these do not work without a mains supply.

Mobile phone systems did not hold up. On most networks, the base station (the transmitter that provides the radio signal to communicate with phones in that area) is powered from the local 230V electricity supply. Some have a battery back-up that continues to provide a service for an hour or two but few, if any, cope with the 30-hour loss or supply experienced over much of Lancaster. Inevitably, the loss of a mobile signal resulted in the inability to send or receive text messages or to use 3G and 4G internet services.

Most domestic internet connections were also lost. This is because the equipment case (usually on the pavement) that houses the routers linking the high-speed fibre connections with the copper wires going to individual houses is powered from the 230V supply.

The loss of communication services was one of the most significant problems reported by many people.

Local radio

During the floods and the loss of the electricity supply, local radio was the best way of finding out what was going on. The first challenge for many people was to find a battery or wind-up radio capable of receiving the FM band, as the local DAB radio transmitter was off-air. The second challenge was to find suitable batteries. The third was to decide which of the dozen or so FM channels available in Lancaster was most likely to include local news. On a traditional radio, of the sort you find in the attic, there is no digital display of channel name and normally the only way to look up frequencies is to use the internet.

BBC Radio 5 live sent a reporter to Lancaster and, much later, he returned to the studio in Blackburn having been unable to broadcast due to the lack of any mobile signal. Initially, other BBC regional channels, based in Kendal or Salford, had similar problems but eventually sorted out an anchor with local knowledge and reporters on site.

The star performer was *The Bay* radio. Their studio is on the Quay overlooking the river. The ground floor flooded but they set up a temporary studio on an upper floor with a generator power supply. However, their only link with the outside world was via a single phone line. They sent one of their reporters home, to Heysham, which still had power, to look at the internet and phone in to say what she could find out that could be relayed to listeners. A second source of information came from listeners who phoned in with something interesting – useful snippets such as where in Morecambe it was possible to get wireless reception or which roads were open.

Most of the local participants at the workshop said that they had listened to *The Bay* as their key news feed. It is perhaps ironic that, in a society with huge commitment to digital infrastructure, the most reliable source of news was a commercial station using technology that would have been familiar to the engineers on the 1960s *Radio Caroline* pirate radio ship.

Figure 9: Broadband router – reliant on mains electricity

Effects on schools and universities

HEAD TEACHERS IN THE LANCASTER AREA HAVE DEVELOPED AN EFFECTIVE NETWORK WHERE THEY DISCUSS COMMON PROBLEMS AND THIS WAS VERY ACTIVE ON SUNDAY 6 DECEMBER

Schools are dependent on electricity. Staff expect to be able to use computers, interactive white boards, music players and other equipment in the classroom. Security depends on access control systems which, because of the possible need for emergency evacuation, default to 'unlocked' in the absence of a power supply. Electric lighting is essential in December. Fire and intruder alarms and emergency lighting rely on a supply of electricity. At one Lancaster primary school, the control room receiving intruder alarm messages from the privatised system is in Belfast. It is unlikely the operator had the benefit of local knowledge and communication with school staff did not work well.

Many school buildings are old and poorly insulated so, in the event of a loss of power, cool down quickly; children cannot be expected to spend their school day in unheated buildings. Schools are now expected to provide a hot meal at lunch time and some also provide meals or snacks at other times of the day. The facilities to prepare these are almost always dependent on electricity.

Electrical systems are also vital to communication. Safety plans are based on the assumption that the school can get in touch with emergency services and parents. The usual means of communication with parents is by text message or email.

Pupil safety on the journey to or from school also depends on an electricity supply to street lights, pedestrian crossings and temporary speed limit signs. Several of the primary schools in Lancaster date from the 19th century and are on main roads where these facilities are important. On 6 December, they were not working.

At one time, the council's local education office might have been expected to take decisions such as whether to close local schools due to bad weather. With recent changes to the way in which schools are organised, there is no longer a local body to take these decisions and the Department of Education and its associated agencies or the head offices of academy chains are too remote to be able to make decisions based on local factors, which thus fall on head teachers.

Head teachers in the Lancaster area have developed an effective network where they discuss common problems and this was very active on Sunday 6 December. The most significant problem reported was that they did not know what was happening and when the electricity supply might be restored. They had heard that there was a *Gold Command*[1] that was providing briefings to the emergency services and the hospital but they were not included in this network and had no greater access to information than other members of the public. Those who lived outside the affected area were able to access Electricity North West's (ENWL) *Twitter* feed but this was of limited use in making decisions a day or two ahead. The inability to communicate with colleagues in the affected area exacerbated their difficulties. One head teacher living 20 miles from her school who received a message that an intruder alarm had operated was unable to contact colleagues living locally to ask them to investigate and, due to the floods, was unable to make the trip to the school herself.

The head teachers decided that they had no choice but to close their schools in the affected areas. The next problem was how to inform parents and other members of staff. One of the most effective options was to contact *The Bay* local radio station, using a pre-arranged password to prevent hoax messages, and ask them to announce the

1 A gold-silver-bronze command structure is used by emergency services of the United Kingdom to establish a hierarchical framework for the command and control of major incidents and disasters. The so-called 'platinum control' is government level (Cobra).

Figure 10: University wind turbine

LANCASTER UNIVERSITY HAS ABOUT 12,000 STUDENTS, 7,000 OF WHOM LIVE ON CAMPUS.

DURING THE 1984 – 1985 MINERS' STRIKE, WHEN THE GOVERNMENT CUT BACK ON ELECTRICITY GENERATION AND INTRODUCED ROLLING NATIONWIDE BLACKOUTS, STUDENTS STAYED IN THEIR ROOMS AND USED CANDLES. SINCE THEN, HEALTH AND SAFETY STANDARDS HAVE MOVED ON

closure, hoping that the message would travel by word of mouth between parents. Many schools also put up posters on the school – in one case written with marker pen on a pillow case tied to the railings – telling parents that the school would be closed until Wednesday, 9 December.

School managers recognised that it was very fortunate the power cut had occurred on a Saturday evening. They had all of Sunday to decide what to do and to make plans. Had the power cut occurred at 10am on a Monday, after parents had dropped off their children and gone to work, the options available to them would have been more limited.

Lancaster University has about 12,000 students, 7,000 of whom live on campus. During the 1984 – 1985 miners' strike, when the government cut back on electricity generation to conserve coal stocks and introduced rolling nationwide blackouts, students stayed in their rooms and used candles. Since then, health and safety standards have moved on. Candles are banned in rooms because of the fire risk; student residences have to be fitted with emergency lighting and smoke detectors.

Emergency lighting systems relying on batteries are designed to ride through a short interruption of supply or to give occupants time for an orderly and well-planned evacuation in the event of a more serious event. After about three hours, the batteries are exhausted. The fire detector system runs for longer but still for less than a day. At 11pm on Saturday, it was decided that the safest plan was to leave students in their accommodation, despite the lack of emergency lighting.

By 11am on Sunday, the news from ENWL was that the power was likely to be off until Tuesday evening, so the decision was taken to close the university a week early. However, the usual way of communicating with students is email or a notice on the university website. With power supplies restricted to a few buildings, Wi-Fi was only available sporadically across the campus and many students' phones or tablets had flat batteries – so the university staff reverted to the more traditional technique of knocking on doors. Communicating with students living in flats in the city was more

difficult and relied partly on a face-to-face briefing of students on campus and hoping that they would pass on the message.

Inevitably the message became corrupted. According to the police, a crowd of several hundred overseas students arrived at Lancaster police station expecting to find transport.

Even without the problems of communication, changing travel plans three weeks before Christmas when floods and landslides had disrupted roads and railways would have been difficult. For UK-based students, there would be little chance of buying a cheap rail ticket and for overseas students rescheduling a long-haul flight would have been a major task, if not impossible.

The situation was not made any easier by the closure of Lancaster railway station from dusk to dawn. On the Sunday, there were no trains on the West Coast Main Line (WCML) north of Preston. By Monday, some trains were running but only stopping at Lancaster station during daylight hours as there was no platform lighting. A radio bulletin at about 6pm said there would be no more Virgin trains between Preston and Glasgow before Wednesday. A couple of hours later a train could be seen heading for Glasgow – but perhaps it was operated by First TransPennine Express or Northern Rail, not Virgin; or perhaps it was going only as far as Carlisle or on the coast route to Barrow? With multiple train operators, the situation is not straightforward even for someone familiar with UK railways – for overseas students, it is likely to be far more confusing.

Because of the uncertainty about services at Lancaster station, the university decided to hire coaches to take students who wanted to leave to Preston. Students who wanted to remain on campus were accommodated in a 'place of safety' in one of the buildings that was fed by a diesel generator.

Power was restored to the university on Monday and managers were left wondering whether they had made the correct decision the previous day. At 3.56pm, a second failure at the substation dispelled these fears. The electricity supply was finally restored to the university on Wednesday with staff asked to go in on Thursday, although ENWL asked the university to severely limit its peak demands for the rest of the week.

The university has a 2 MWe combined heat and power (CHP) plant and a 2 MW wind turbine. With the storm, there was no shortage of wind. However, the system is not designed for 'islanding' (operating the university system as a self-contained system, without external power) and there is no active load control to manage demand to match supply, so when the 11 kV feeders were lost, everything shut down. It would not be very difficult to redesign the university network so that it could operate as a self-contained system or 'island' but this would involve expensive and disruptive restructuring of much of the 415 V electricity network. If a repeat of the events during Storm Desmond were likely every year or two, it would not be difficult to justify the investment; with a probability of less than 1 in 100, there would have to be an additional incentive.

The health service and care providers

Figure 11: Royal Lancaster Infirmary

Like most district general hospitals, Lancaster Royal Infirmary has standby diesel generators. To allow for the possibility of generator failure, they are duplicated so that it has, in effect, twice as much generation capacity as it can use. It also has a fuel storage capacity for 14 days' use. Thus the hospital should have been capable of carrying on as normal with no disruption to its operations.

However, the environment in which the hospital was operating was far from normal. The health service is structured so that a patient's first port of call is their GP, the 111 call centre or a pharmacy. Access to these was disrupted and so anyone seeking treatment or advice went to the hospital A&E department, which quickly became overloaded.

Because alternative service providers were unavailable, people phoned A&E with trivial questions, such as enquiring where they could obtain paracetamol. As one of the few sources of information, the hospital became the 'go-to' place for any queries – including how to heat baked beans when the electric cooker was not working.

Although bizarre requests are the easiest to remember, the hospital also received a large number of more serious requests, such as problems with home dialysis or to dispense repeat prescriptions as pharmacies were closed. The hospital pharmacy staff provided a good service under these conditions but nevertheless operated at significantly heightened demand.

More generally, the hospital was seen by many as a community centre. People with nowhere else to go wandered in off the street. The canteen served a record number of meals. A group of students arrived with a six-way extension lead and their mobile phone/tablet battery chargers which they connected to the first free 13A socket they could find. As a community centre, it was serving a valuable function – increasingly important as other facilities were closed – but well removed from its core business.

The health service supports an increasing number of people at home; however, it is dependent on a reliable electricity supply and mobile phone coverage. Some people have serious chronic conditions requiring equipment for such treatments as dialysis or oxygen therapy. Others with mobility problems need stair lifts, powered help to get out of bed or other mobility support. All these use mains electricity. Many frail people use a personal alarm system, in case they fall or are taken ill; these usually have a base station connected to a landline and are powered from the mains. If the mains supply fails, an alarm is initiated; if several hundred alarms come in simultaneously, the local call centre is overwhelmed. Add

Figure 12: Laurel Bank Care Home (photo: courtesy Laurel Bank Care Home)

to this that home care providers, who are often first responders to the alarm systems, usually communicate with their staff via a mobile phone and it is clear that the home care system can be highly susceptible to a loss of supply.

There were conflicting views over how the community should (or could) react with frail and elderly people in their homes. On one hand, if neighbours are well known to an elderly person, they are likely to be welcome if they pop round during a power cut to check everything is fine; on the other, no one wants neighbours who hardly know their name summoning the police to force an entry because they have not been out for a few days. ENWL maintains a register of vulnerable people who might need special provision when there is a power cut but there is no guarantee that this is complete and there are important privacy and security issues around keeping a comprehensive list of vulnerabilities.

A nursing home brings together people who need greater care than they can receive in their own homes. Laurel Bank is a purpose-built nursing and residential home in Lancaster with 70 single en-suite bedrooms. It provides for a range of needs: from day-to-day care for those who are no longer able to manage at home through to specialist 24-hour nursing care for those with complex care requirements.

During the blackout, Laurel Bank lost heating, hot water and lighting – including residents' en-suite facilities. Personal alarms, lifts and phones through the internal switchboard ceased to function, so a staff member brought in a wired phone which was plugged into the Fax line. Infirm residents who are usually helped from their beds by electric hoists had to be lifted by staff. Electrically-tilted beds and chairs no longer worked. Although the kitchen is fitted with gas cookers, these could not be used because they are interlocked with the electrically-powered extractor fans. The chef built a barbeque in the garden (during the tail end of Storm Desmond) to prepare a meal for the residents. The family of one resident brought a camper-van and prepared hot drinks on the portable gas stove in its kitchen and neighbours brought hot food.

Managing a care home on a cold, gloomy winter's evening with no light or heat, with very limited facilities for cooking or for residents to wash and none of the usual distractions, such as television, was a challenge.

Equally challenging was running an overnight shelter for homeless people. For several winters, volunteers at Christ Church have opened the doors of the church hall during the night to homeless people. Despite the lack of electricity, they decided not to change the routine. Cooking is by gas so they could still make a hot meal and, with a combination of head torches and hand-held battery lights, they were able to see what they were doing.

To some people, a mobile phone is still seen as a luxury; to many homeless people it is an essential. To contact the job centre or other official body, the choice is usually a phone call or, sometimes, email. For people with no fixed abode, conventional mail is difficult and to be tied to publicly available internet terminals in libraries is very limiting. As for other groups, the failure of communications was a significant loss.

Being homeless in a city during winter is a difficult life. Being homeless in a city with no street lights, no illuminated shop fronts and few people about is worse, causing unusual levels of fear and vulnerability. The volunteers (who had acted instinctively) therefore considered they had made the right decision. However, after the event, not all members of the parochial church council (PCC) were in agreement. The PCC members are the trustees and have responsibility for the safety of the volunteers and others on church premises. Some of the guests in the shelter can have challenging behavioural issues, and the policy is that volunteers on duty must have an accessible phone, in case there is a need to call for assistance. With mobile and cordless phones inoperable, the nearest wired phone was in the church vestry – on the other side of three locked doors. The volunteers saw the risks to the guests in an electricity-less city; a number of the trustees saw the risks to the volunteers. How these can be balanced is a matter of judgement.

Retail businesses and banking

Figure 13: Booths supermarket

The retail sector was severely affected both by the floods and, more widely, by the loss of electricity. Four supermarket chains operate in the Lancaster area – Sainsbury's has a branch in Lancaster next to the river; in Morecambe, on the other side of the river, there are Asda, Aldi and another Sainsbury's. Booths, a local supermarket chain, has a branch in south Lancaster about a mile from the university.

On Sunday morning, there were restrictions on traffic across the river and Sainsbury's was flooded. Some stores, including Sainsbury's Local, handed out limited ranges of free food and essentials because they did not have the means to accept payment. Booths had brought in a generator in the early hours of the morning and was able to open as usual. As the only grocery store open in Lancaster, it was very busy all day and called up any extra staff who lived locally and were able to come in. The electronic checkouts were working but the card payment terminals that work through the internet were not operational, so they could only accept cash payments. However the ATM cash machine still worked and, despite a busy day, had not been exhausted by closing time at 4pm. It seems that the ATM used a conventional phone line, rather than the internet, to contact issuing banks and, as it was fed from the diesel generator, had a working power supply.

By 4pm, there were still many people wanting to buy groceries but, to comply with Sunday trading regulations, the supermarket closed. It was not obvious which national or local body had the power to relax these laws in an emergency.

Santander Bank has a branch on the university campus. Like most banks, it has comprehensive security systems including intruder alarms and CCTV systems sending images for remote monitoring. To ensure staff safety, there are rules that, if the intruder alarm indicates that the bank might have been entered illegally, the CCTV has to be monitored to ensure that no intruders are still on the premises before the branch is unlocked.

The bank has an uninterruptable power supply (UPS) using a battery to keep essential systems live during a power cut of a few hours. After that, some systems cease to operate or default to an alarm condition and staff are not allowed to enter the premises until they have been checked by security. By Monday morning, power had been restored but it was several more hours before business was able to resume.

Transport

LANCASTER BUS STATION, WHICH HAD BEEN FLOODED, WAS CLOSED BUT THERE ARE ESTABLISHED ALTERNATIVE STOPPING POINTS. AT NIGHT, THERE WAS NO STREET LIGHTING BUT PASSENGERS COULD SEE TO BOARD BY THE INTERNAL LIGHTS

Lancaster is on the West Coast Main Line (WCML) of the rail network. The WCML is electrified at 25 kV but the power for trains in Lancaster is drawn from the 132 kV lines at feeder stations near Garstang and Kendal, rather than from the local network. Thus trains could continue to operate despite the loss of power in Lancaster.

Apart from the power supply, the railway needs electricity for signalling and control systems. These systems are normally fed from the local 415 V network but there is a backup where power is taken from the 25 kV traction supply and transformed down to 600 V to supply the signalling system. The signalling system was working.

Most railway stations in Britain have auxiliary supplies taken from the local electricity network. These feed platform lighting, heating and lighting in offices and control rooms, de-icing heaters on points, the public address and information systems, ticket machines, lifts and many other pieces of equipment. With the loss of the supply in Lancaster, all these stopped working. Without lighting or any of the normal means of communicating with passengers, the station operator decided it would have to close at dusk.

The bus service was more self-contained. Once the bridges across the River Lune had been reopened, buses could operate almost normally. For a week or so, Lancaster bus station, which had been flooded, was closed but there are established alternative stopping points. At night, there was no street lighting but passengers could see to board by the internal lights.

There were some problems in the depot. Buses are usually refuelled by electric pumps, which were not working. However, the depot has retained some hand pumps which could, with effort, be used to refuel the fleet. The offices were dark but bus headlights were able to pick out key locations and staff had torches. Much workshop equipment relies on compressed air, which is produced by electricity, but maintenance schedules could be delayed by a few days without significant risk.

Lancaster's diesel-powered bus service was sufficiently resilient to survive for several days without an electricity supply and the management approach was to keep the service going. It is unlikely that a fleet powered by electricity or hydrogen would have been quite so resilient.

Gas, water and sewage services

RESIDENTS IN SOME OF LANCASTER'S NEW CITY CENTRE ACCOMMODATION DISCOVERED THAT, WITHOUT ELECTRICITY, THEY HAD WATER NEITHER FROM THE TAPS NOR FOR FLUSHING THE TOILET

The gas network maintained supplies in Lancaster without any serious problems. Many years ago, when there was a town gas supply, there was little need for electricity. These days, the national gas network uses electricity for some pumping stations and pressure reducing stations, as well as for powering instrumentation and control systems. In the future, smart gas meters will use mains electricity for meter reading.

National Grid's gas network division has recourse to portable generating sets, if it proves necessary, to provide a power supply to a pumping station or other infrastructure site. Many of the assets used in supplying Lancaster with gas are outside the area affected by the loss of supply, which mitigated the effects. Overall, the arrangements seem to have been largely effective in the Lancaster area.

Water and sewage represent more of a problem. Lancaster's water comes from two large reservoirs 100 metres above the city. Pumps are used to refill the reservoirs but they can store sufficient water for many days use and the pumps are outside the affected area. The situation would have been very different in a community reliant on water towers which have a much lower capacity. Between the reservoirs and the consumer, there is a water filtering and chlorination plant which uses electricity. Whatever arrangements were made seem to have been effective as there were no reported failures of the water supply network.

The same cannot be said for arrangements in all buildings. Blocks of flats use booster pumps to get water to higher floors. Residents in some of Lancaster's new city centre accommodation discovered that, without electricity, they had water neither from the taps nor for flushing the toilet. There were also reports that inhabitants of some environmentally-friendly buildings that use 'grey water' (second-hand water from showers or washing) to flush toilets discovered that, without electricity, there was no toilet flushing.

Although engineers try to arrange sewage systems to use gravity flow as far as possible, there are many places where electricity is used to pump raw sewage to the treatment works or in the works itself. Many of these are fed from the local 415 V supplies at the roadside. United Utilities, the local operator, has standby generators that can be used to provide backup supplies. During the workshop, there was not enough time to discuss this topic in detail but the emergency arrangements seem to have been satisfactory.

The community's reaction to power cuts

Figure 14: Free food (photo: courtesy of Electricity North West)

The experience of most workshop participants was one of local people coming together to support each other during the power cuts. There were some reports of 'looting' in the more sensationalist daily papers, but the view of the police service was that this was very low level and might better be called 'opportunistic theft'.

There was a genuine community spirit. In the city centre, ENWL provided free hot food from a roadside stall and a local restaurant, rather than seeing frozen supplies bought for the holiday period go to waste, provided free Christmas dinners.

However, it has to be questioned whether the experiences of the workshop participants were typical of all members of the community. We should perhaps more explicitly differentiate between the impacts on different groups of people. Fit young people were probably less at risk of various additional harms than those who were already vulnerable for a one reason or another. These vulnerabilities included physical frailty and dependence for essential health services on electricity. Talking with people in the city, some spoke of being implicitly afraid of violence, perhaps as a result of isolation.

Police teams were drafted in from the surrounding areas to provide a presence in localities where residents might need reassurance and also helped other local services to contact vulnerable people – at least those who were known to them.

The situation was probably helped by the timing of the power cut (10.45pm on Saturday) and by the mild and sunny weather the following day that gave people time to plan what to do. Had it occurred during the working week, after parents had dropped off their children at school and gone to work, the situation would have been more stressful.

The rapid actions by ENWL in locating 75 large generators, from as far away as the West Country and Northern Ireland, and arranging for them and their accompanying staff to come to Lancaster limited the duration of the worst of the outage. Had a similar event occurred elsewhere a couple of days previously, it is likely that the generators would already have been 'spoken for' and that many consumers would have experienced three or four days without any electricity. A heavy snowstorm or other travel disruption could also have prevented the arrival of back-up power.

Media reports of some major overseas power cuts have recorded increases of violence and looting. What differentiates an event that enhances community cohesion (as described by many during Storm Desmond in Lancaster) from one that encourages violence and criminal behaviour is a subject worthy of further research.

What can we learn from the events in Lancaster?

Figure 15: Preparing a fall-out shelter (from *Protect and Survive)*

Where should resilience be located?

Storm Desmond demonstrated the need for greater resilience in several systems on which people rely – in particular communications systems. This raises the question of where that additional resilience is best located. The 1970s leaflets *Protect and Survive*, advising citizens how to survive nuclear war, placed the responsibility for resilience squarely on individual households. The leaflet recommended that people should brick-up their windows, lay in stocks of food and water for several weeks, construct a fall-out room, and so on. One could adopt a similar policy in relation to loss of electricity – resilience is the responsibility of those affected: 'if you use electrically-powered medical equipment, you may wish to consider owning a petrol generator in case the power goes off' but often the most at risk may be the ones least able to invest directly in effective resilience.

At the next level, it would be possible to place the responsibility on a service provider. One way would be for Ofcom to place a requirement in mobile phone operator licences that they had to continue to provide a service under conditions of loss of power for a certain number of days. Alternatively, there could be a regulatory obligation on the distribution network operator (DNO) to provide duplication to maintain a supply of electricity under such circumstances.

Another option would be for regulators to allow a much greater rate of failures of the electricity supply and/or communications systems but to overlay this with a rapid-response mobile back-up system that could restore services on a temporary basis (such as TWEETHER, discussed later), while the main systems are being repaired. However, within the privatised telecoms sector, it is not clear where this responsibility should, or even could, reside.

It is not possible to choose one of the above strategies in isolation. Some, such as requiring mobile phone companies to maintain a service for several days without external power or requiring a DNO to hold 100% standby power for a large area, could be prohibitively expensive. The scope of emergency provision will depend on the scale of the disruption envisaged. ENWL

IN CITIES LIKE LAGOS OR BAGHDAD, WHERE 12 HOURS OF POWER CUTS **PER DAY** ARE NOT UNCOMMON, IT IS NOT DIFFICULT FOR CONSUMERS TO MAKE A CASE FOR INVESTING IN STANDBY GENERATION. IN BRITAIN, FEW PEOPLE ARE PREPARED TO PAY FOR EQUIPMENT THAT IS LIKELY TO BE UNUSED FOR YEARS ON END

had to scour the UK to find 75 generators to supply Lancaster; providing 750 to supply Birmingham, for example, would be a problem of a different order of magnitude. Coping with a 'black start' of the whole of Great Britain's electricity system would be another two orders of magnitude in scale.

The electricity supply system in Great Britain is generally very reliable. The Storm Desmond loss of power in Lancaster was noteworthy because of the number of people affected and the duration. Most consumers experience power cuts of no more than a few hours per year, if any. In cities like Lagos or Baghdad, where 12 hours of power cuts per day are not uncommon, it is not difficult for consumers to make a case for investing in standby generation. In Britain, few people are prepared to pay for equipment that is likely to be unused for years on end. It is clear that additional resilience is needed; where it should be located in the overall system requires more analysis.

The costs of loss of supply

Experiences during Storm Desmond raise important questions about how the industry and the regulators consider the 'value' of the loss of an electricity supply – described as 'value of lost load' (VoLL). Traditionally, this is based on asking consumers what they think the supply of electricity is worth, generally by a stated preference choice experiment which is used to estimate the VoLL in terms of willingness-to-accept (WTA) payment for an outage and willingness-to-pay (WTP) to avoid an outage for domestic and small business electricity users.

Reviewing the conventional methodology, such as the 2013 work by London Economics on OFGEM's website,[2] it appears that this process fails to account for many of the issues that have been raised by participants in this workshop. Asking individuals to put a value on something of which they have no experience and have never considered seriously cannot be described as a rigorous analysis. As a report by the Royal Academy of Engineering points out, "The large variation between different estimates of VoLL means that, from existing research, no concrete conclusions can be made on the cost of electricity supply interruptions. It is important to note that VoLL is not a value-neutral measure; it is a measure of people's *perceptions* of the value of a unit of electricity."[3]

A more realistic valuation could be assessed by analysing some of the issues discussed during the workshop. It could also include an estimate of some of the events, such as violence and looting, that have been seen in similar events overseas but fortunately were not seen in Lancaster.[4]

Communications and local radio

One common theme of all the organisations affected by the loss of supply was the problem of reliable communication. In the past, when services, such as water,

2 *The Value of Lost Load (VoLL) for Electricity in Great Britain*, London Economics, July 2013 www.gov.uk/government/uploads/system/uploads/attachment_data/file/224028/value_lost_load_electricty_gb.pdf

3 *Counting the cost*, The Royal Academy of Engineering, Nov 2014 www.raeng.org.uk/publications/reports/counting-the-cost

4 Work at Lancaster, newly consolidated in the Violence & Society UNESCO Centre, includes the measurement of violence and the quantification of its impact in monetary terms.

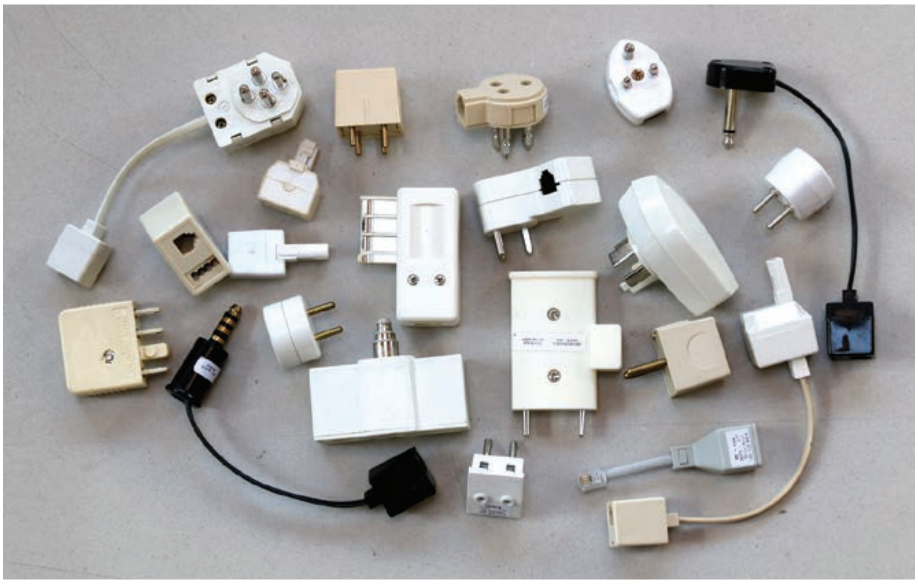

Figure 16: Phone adaptors from the 1990s

gas, sewage disposal and electricity were provided by the local authority, much communication could be by word of mouth. With privatisation, rationalisation and the outsourcing of non-core activities, it is not surprising to find the administration for the Lancaster Magistrates' Court being carried out in Preston or the intruder alarms in a Lancaster primary school being monitored in Belfast. These arrangements rely on reliable channels of communication. During Storm Desmond, the reliability was found wanting.

There was a particular problem for the managers of businesses in contacting their staff. At least one organisation resorted to sending someone by car to knock on doors or put cards through letterboxes. Many employees of well-established local businesses, such as Booths, live locally and can be contacted personally. The university could contact staff who live in outlying villages that were not affected by the loss of supply but were unable to contact many of those living in Lancaster.

A second common theme could be summarised as 'no one told us anything'. From what was discussed at the workshop, there was a *Gold Command* in Lancaster that was communicating with the emergency services (fire, police and the hospital) as well as ENWL. Outside this select group, people had to rely on what was publicly available. Communication depended to a great extent on social media, principally Twitter, and on posts on organisations' websites. Many people said that Twitter was a very useful tool for finding out what was happening. Unfortunately, it was not available in flooded areas, where internet and mobile phones were not working. As an emergency communications medium, Twitter is not something that can be relied on.

Those responsible for the safety of 250 primary school children or 12,000 undergraduates (representing 10% of Lancaster's population) considered that they needed a better source of information than an unreliable Twitter feed. The workshop was not the place to discuss how this could be provided and who should be responsible but there was a clearly expressed need for something better than what was available during Storm Desmond.

Many people in the workshop said that they were surprised by the importance of Wi-Fi and mobile phone coverage to so many aspects of life. News is delivered through the internet, not by paper; students' timetables are on the internet; Apple Pay requires a working phone; phone numbers are stored in a SIM card, not a paper phone book, and so on. 20 years ago, anyone involved in international business would travel with a bag of adaptors to connect a laptop to whatever local wired telephone network was available. Now everyone expects high-bandwidth Wi-Fi coverage everywhere and all the time.

The Department for Culture, Media and Sport has a policy 'to provide superfast broadband coverage to 90% of the UK by early 2016 and 95% by December 2017'. The better the internet becomes, the more people will rely on it. Thus the challenge for policy makers is to plan what to do when the system falls over. The events in Lancaster demonstrated one of the downsides of over-reliance on the internet.

Internet and mobile phone providers are in a difficult position, when it comes to providing a reliable service in the absence of an electricity supply. Storm Desmond affected communications in Lancaster for about a week (2% of the year). Across the UK,

THE BETTER THE INTERNET BECOMES, THE MORE PEOPLE WILL RELY ON IT. THUS THE CHALLENGE FOR POLICY MAKERS IS TO PLAN WHAT TO DO WHEN THE SYSTEM FALLS OVER. THE EVENTS IN LANCASTER DEMONSTRATED ONE OF THE DOWNSIDES OF OVER-RELIANCE ON THE INTERNET

Figure 17: Delegates listening to a speaker from Morecambe Bay Hospital Trust

> RATHER THAN MAKING THE MOBILE INTERNET MORE RESILIENT, IT MIGHT BE WORTH INVESTING IN AN EMERGENCY SYSTEM THAT COULD BE BROUGHT TO THE AFFECTED NEIGHBOURHOOD IN HALF A DOZEN VANS, MUCH LIKE THE EMERGENCY GENERATORS WERE BROUGHT TO LANCASTER

there might be one event like this per year. The population of Lancaster represents about 0.2% of the UK population so, on average, an event might affect 0.2% of the population 2% of the time. It is difficult to make a financial case for standby arrangements that are used 0.004% of the time.

There are also practical problems. A typical mobile phone base station has a power demand of around 500 W. The battery of a typical electric car, which costs several thousand pounds, has a capacity of 20 kWh, so it could keep a base station running for about 40 hours. While the black market for mobile phone base stations can only be described as 'niche', there could be a much larger market for high capacity batteries (for caravans or for their scrap value) or for portable generators. Security and maintenance could add substantially to the costs of providing standby power for base stations.

Rather than spending large sums of money on making the mobile internet more resilient, it might be worth investing in an emergency system that could be brought to the affected neighbourhood in half a dozen vans, much like the emergency generators were brought to Lancaster.

Lancaster University Engineering Department is leading the EU Horizon 2020 TWEETHER programme to build a novel rapidly deployable millimetre wave communication system. The TWEETHER system will provide economical broadband connectivity with a capacity up to 10 Gbits/km^2 and distribution of hundreds of Mbps to tens of terminals. This will allow the capacity and coverage challenges of current backhaul and access solutions to be overcome.

Following the impact of the loss of supply in Lancaster, the Engineering Department is considering how best to deploy high capacity base stations (transported on vehicles) to form an emergency network where and when needed. In particular, they would be invaluable when the existing network is completely down and cannot be reactivated in the short term. Obviously, each base station will need its generator but this will be far less expensive than providing standby power supplies, used very infrequently – if at all, to all cabled base stations. The transmission would be wireless and thus independent from the soil status and would not rely on local power supplies to routers or other components.

The TWEETHER system is one way in which it could be possible to reconcile a society reliant on 'always-on' access to broadband with a fixed infrastructure that cannot easily be made proof against rare but devastating events at an affordable cost.

During the workshop, there was discussion of the Tetra (Terrestrial Trunked Radio) system used by UK emergency services. This is a technology that is half way between a mobile phone system and a walkie-talkie. By current standards it is out-dated technology and, as it runs at only 7.2kbs, is poor at transmitting mobile data.

Over the coming year, it is planned to replace Tetra by a new Emergency Services

AN ALTERNATIVE TO USING A TERRESTRIAL RADIO NETWORK IS TO USE SATELLITE PHONES. ONE OF THE PARTICIPANTS DESCRIBED HOW HIS ORGANISATION GOT OUT ITS SATELLITE PHONES FOR THE EMERGENCY, ONLY TO DISCOVER THAT NONE OF THE STAFF KNEW HOW TO USE THEM

SUBSEQUENT REORGANISATION, NATIONALISATION, PRIVATISATION, RESTRUCTURING AND THE CONTRACTING OUT OF SERVICES, RESULTED IN THE SERVICES NOW BEING RUN BY A LARGE NUMBER OF ORGANISATIONS, CONTRACTORS AND SUBCONTRACTORS, WITH NO ONE HAVING AN OVERALL VIEW OF 'THE SYSTEM'

Network. This will use the commercial 4G network which will give a dramatic improvement in speed and also the ability to send high-definition pictures and data. However, it will use an existing network that, if the experience in Lancaster is representative, is not resilient in the sort of situation where the emergency services will be most in need a reliable means of communication.

An alternative to using a terrestrial radio network is to use satellite phones. One of the participants in the workshop described how his organisation got out its satellite phones for the emergency, only to discover that none of the staff on the ground knew how to use them. Maintaining trained operators for the one week every generation when the phones might be needed may be appropriate for certain military planners but is unlikely to be a priority for most commercial organisations.

Complex and brittle systems

One of the issues raised by almost all participants in the workshop was the failure of communications both between and within organisations. This raises the question of the resilience of not just mobile phone networks or the internet but of the overall communications system.

In the first half of the 20th century when telephone and electricity networks were first established, Lancaster Corporation acted as the 'system architect', although the phrase was not used at that time. The Corporation ran the gasworks, the water network, the tramway and the electricity network. In an emergency, the Corporation would have co-ordinated how these various services worked together and staff could have been transferred from one to another as the need arose.

Subsequent reorganisation, nationalisation, privatisation, restructuring and the contracting out of services, resulted in the services now being run by a large number of organisations, contractors and subcontractors held together by a web of scores of commercial contracts, with no one having an overall view of 'the system'.

Sydney Dekker, in his book *Drift into Failure*,[5] wrote "The growth in complexity in society has got ahead of our understanding of how complex systems work and fail. We are able to build things – from deep sea oil rigs to collateralised debt obligations – whose properties we can model and understand in isolation. But, when released into competitive, nominally regulated societies, their connections proliferate, their interactions and interdependencies multiply. And we are caught short."

Considering the situation in Lancaster during Storm Desmond, it is worth unpicking this statement. Systems engineers define a *system* as:

- any collection of people, machines and processes that co-operate to accomplish a common goal
- the goal only emerges when the components co-operate – it is not a property of any one of them.

Years before Storm Desmond, academics were describing the characteristics of a complex system in the following way:

- large numbers of participants sharing responsibilities
- wide geographical/organisational distribution of a single critical system
- dependencies between various critical systems
- unplanned (and unplannable) human interactions

5 Sidney Decker, *Drift into Failure – from hunting broken components to understanding complex systems*, Ashgate Publishing, 2011.

Figure 18; Lancaster Castle

- many actors with incentives to optimise their own corner of the system
- system continually adapts to fit into its environment.

This sums up the situation that was experienced in Lancaster. The functionality of the communications system depended on a large number of different players, many of whom are located miles from Lancaster. There are critical dependencies between the electricity system, the internet and the mobile phone network. There was no formal structure of how different bodies were expected to communicate. Some players had commercial or regulatory incentives – either to maximise profit or to minimise their regulated asset base – that worked against total system resilience. As new apps have become available, the way in which people communicate has changed without any strategic direction.

Storm Desmond demonstrated the conflict between a resilient system and an efficient system. An **efficient** system is designed and operated to produce the maximum possible output for the minimum (usually financial) input. Depending on how efficiency is measured, it is usually necessary to consider the performance for only 95% or perhaps 99% of the time. If the performance drops dramatically for the odd day every few years, this will not detract greatly from the average efficiency. By contrast a **resilient** system tends to be one with plenty of 'headroom' so, if it is called on to exceed its normal performance to cope with a peak in demand caused by failures elsewhere, it has the ability to do so. The UK needs to decide where it wants its infrastructure systems to sit on the resilient-efficient spectrum and to bear this in mind when changing the engineering, regulatory or management structures of the industries concerned.

Users, suppliers and regulators might also consider retaining a basic capability with sufficient power supply backup and resilience for use in an emergency – for example, an internet service provider could retain a 56 kbps dial-up service restricted, in some way, to prevent users trying to download a video or upgrade Windows through it. More challenging might be for potential users to retain modems and other necessary hardware and the knowledge of how to use them.

Figure 19: Lancaster's Victorian Town Hall

A community focus

Several centuries ago, in times of stress or natural disaster, Lancaster's population might have turned to the castle or the parish church as a bastion of stability in a confusing and frightening world.

By the early 20th century, the Town Hall had taken over part of this role as the council provided most of the infrastructure services. For those in work, the large and paternalistic industries provided a point of stability.

Now, for most of us, there is no obvious community focal point to which residents can turn in the event of a civil emergency. It was this that encouraged people to wander into the hospital or that triggered the

IS IT BETTER FOR STUDENTS TO REMAIN IN THEIR ROOMS WITHOUT FIRE ALARMS OR EMERGENCY LIGHTING OR TO BUS THEM TO A RAILWAY STATION AND LEAVE IT UP TO THEM TO FIND THEIR WAY HOME FROM THERE?

arrival of hundreds of students at the police station. Perhaps there should be a formal policy of certain large organisations opening their doors in a civil emergency?

Balancing risk

Several speakers at the workshop spoke of the problems of balancing risk. For example, is it better for students to remain in their rooms without fire alarms or emergency lighting or to bus them to a railway station and leave it up to them to find their way home from there?

Many UK regulations and practices are based on the 1974 Health and Safety at Work Act. This was originally primarily concerned with the obligation of employers for the safety of employees in factories and other workplaces. Section 3 of the Act extended the scope to the safety of non-employees, such as visitors and neighbours. Subsequently, the scope has been extended to cover schools, universities, transport systems, prisons, military establishments and all sorts of areas not envisaged by the Robens Committee who produced the original report.

While the current interpretation of the Act is effective in managing the responsibilities of organisations and businesses, it is more ambiguous in managing risks that might fall between several different organisations. In the case of the students at the university or the homeless shelter, where there was a conflict between the safety of the homeless people and safety of the volunteers, the regulations tend to encourage managements to take the 'safe' option and move the risk from their organisation to another or to the individual affected.

In coping with similar events in the future, it might be helpful for there to be more specific guidance about how best to balance risks of this sort.

Could it happen again?

This loss of supply was caused by an intense storm. Commentators talked about a 'once in a 100 years event'; however the fundamental characteristic of climate change is that the present is – and the future will be – different from the past. In the three months between November 2015 and January 2016, there were seven named storms that affected the UK or Ireland: Abigail, Barney, Clodagh, Desmond, Eva, Frank and Gertrude. All caused wind damage, flooding or both. With increasing climate volatility, it is likely that environmental factors will result in a greater frequency of events that could lead to loss of supply.

Intense storms are not the only possible cause of a blackout. Other natural causes include geomagnetic disturbances or solar flares.[6] There are also man-made causes of a blackout; on 23 December 2015, more than 100,000 people in and around the Ukrainian city of Ivano-Frankivsk suffered a six-hour loss of power caused by cyber-terrorism.[7] A month later, the Israeli power system came under attack from hackers.[8] Much of the UK's electricity infrastructure is in open country where protection from a determined and widespread physical attack would be almost impossible. There are also possible, if improbable, sequences of technical events that could shut down large areas of the national grid. On 30 September 2012, a combination of failures caused a rapid change in frequency that came close to the rate that could have triggered widespread disconnection of generators and power outages.[9]

THE FUNDAMENTAL CHARACTERISTIC OF CLIMATE CHANGE IS THAT THE PRESENT IS – AND THE FUTURE WILL BE – DIFFERENT FROM THE PAST. IN THE THREE MONTHS BETWEEN NOVEMBER 2015 AND JANUARY 2016, THERE WERE SEVEN NAMED STORMS THAT AFFECTED THE UK OR IRELAND

6 www.raeng.org.uk/publications/reports/space-weather-full-report

7 http://phys.org/news/2016-01-cyberattack-ukraine-power-grid.html

8 http://www.haaretz.com/israel-news/.premium-1.699706

9 http://www2.nationalgrid.com/workarea/downloadasset.aspx?id=16968
(please copy this url into your browser)

Conclusions

WE MUST NEVER FORGET THAT THE INTERNET IS DEPENDENT ON ELECTRICITY. WE NEED A REGULAR NATIONAL REVIEW TO KEEP TRACK OF OUR DEPENDENCY AND HOW SOCIETY CAN CONTINUE TO FUNCTION WITHOUT ELECTRICITY

The workshop was an opportunity to learn from what happened in Lancaster and was not intended as an event to make recommendations about what should happen next. However, there are several areas where the effect of Storm Desmond on Lancaster should serve as a wake-up call to bodies involved in the supply and regulation of infrastructure services.

Over the years, we have become increasingly dependent on electronic communication – mobile phones and the internet. Each individual action – for example, doctors replacing paper files by computer systems, a government department ceasing production of hard-copy leaflets and moving to online information systems or the banks phasing out cheque books and introducing contactless cards – sounds like a good idea at the time. However, each such action moves society inexorably towards a greater dependency on the continual availability of the internet. Initiatives like the Internet of Things or Smart Cities will move us faster in that direction.

However, we must never forget that the internet is dependent on electricity. We need a regular national review to keep track of our dependency and how society can continue to function without electricity. If such a review finds that greater resilience is needed, there will have to be a forum to decide whether, for example, it should be provided by the electricity supply industry, internet service providers, the mobile phone industry or the consumer. This is not a decision that can be left to market forces.

At a local level, organisations and businesses need to work out how they could be affected by the loss of electricity and how they could increase their resilience. The experiences of the education and care sectors in Lancaster are particularly relevant.

The electricity grid is being transformed from the structure that has grown up over the last 100 years, where power was supplied by a small number of large coal-fired power stations through a fixed network of cables and transformers, to a large number of passive consumers. Within 10 years, the large coal-fired stations will be closed and we will rely to a much greater extent on distributed generation from millions of wind turbines, solar panels, and other renewables.

At the same time, consumers will be more active with smart meters, intelligent home energy computers, Wi-Fi controlled thermostats, community energy networks and other 'smart' systems. Rather than the grid being a passive system that carries electrical power always in one direction, it will be an active bi-directional network. This additional complexity and the unpredictability of these new systems will inevitably bring additional risks – most will have been foreseen and taken care of, but there may be some that take us by surprise.

Taken individually, each of these hundreds of innovations, from phasing out information leaflets to installing smart thermostats, does not seem to add much to overall risk to society. Taken together, they are changing the risk profile of all consumers, particularly the most vulnerable, dramatically and in ways that have not been fully analysed. The workshop discussed some of the linkages between systems in 2015; these were different from those in 2005 and will turn out to be very different from those in 2025.

Appendix

Lead author

Professor Roger Kemp MBE FREng, Professorial Fellow, Lancaster University

Workshop coordinator

Mary English, Project Manager, Lancaster University

Workshop participants

Bill Johnston	The Bay Radio
Ben Cross	Booths Supermarket (by video)
Jacqueline Stamper	Christ Church homeless shelter
Mick Allen	Department for Business Innovation and Skills
Katherine O'Connor	Department for Business Innovation and Skills
Lindsey Smallman	Department for Energy and Climate Change
Chris Patrick	EE Mobile Networks
Martin Deehan	Electricity North West
Jonathan Morgan	Electricity North West
Karim Anaya	Energy Policy Research Group, Cambridge
Phil Lawton	Energy Systems Catapult
Andrew Haslett	Energy Technologies Institute
Andy Brown	Environment Agency
Sam Bradley	GO-Science
Andrew Cole	GO-Science
Mike Edbury	GO-Science
David Litchfield	GO-Science
Richard Sandford	GO-Science
Elizabeth Surkovic	GO-Science
Mike Dawson	Health and Safety Executive
Duncan Botting	IET Energy Policy Panel
John Cowburn	IET Local Centre
Xander Fare	IET staff
Mark Bartlett	Lancaster City Council
Stuart Hosking	Lancaster Hospital

PC Ben Rooke	Lancaster Police
Diane Dangerfield	Lancaster resident
Kevin Dangerfield	Lancaster resident
Joan Kemp	Lancaster resident
Jan Baastians	Lancaster University
Oliver Bates	Lancaster University
Lauren Brown	Lancaster University
Monika Buscher	Lancaster University
Simon Corless	Lancaster University
Nigel Davis	Lancaster University
Mary English	Lancaster University
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Harry Hoster	Lancaster University
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Rob Lamb	Lancaster University
Andreas Mauthe	Lancaster University
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Katrina Peterson	Lancaster University
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Elizabeth Shove	Lancaster University
Chris Squire	Lancaster University
Mark Swindlehurst	Lancaster University
Sylvia Walby	Lancaster University
Gordon Walker	Lancaster University
Konstantinos Zografos	Lancaster University
Lisa Lothian	Laurel Bank Care Home
Erica Lewis	Office of Cat Smith MP
Stew Horne	Ofgem
Carl St John Wilson	Ordnance Survey
Alan Walker	Royal Academy of Engineering
Sarah Lonergan	Santander Bank
Alison Aylott	Scotforth St Paul's C of E Primary School
Willie McPhail	Stagecoach Bus
Lindsay Wright	UKERC
Dan Trimble	United Utilities
Jack Marland	Work experience student

Photo: the River Lune

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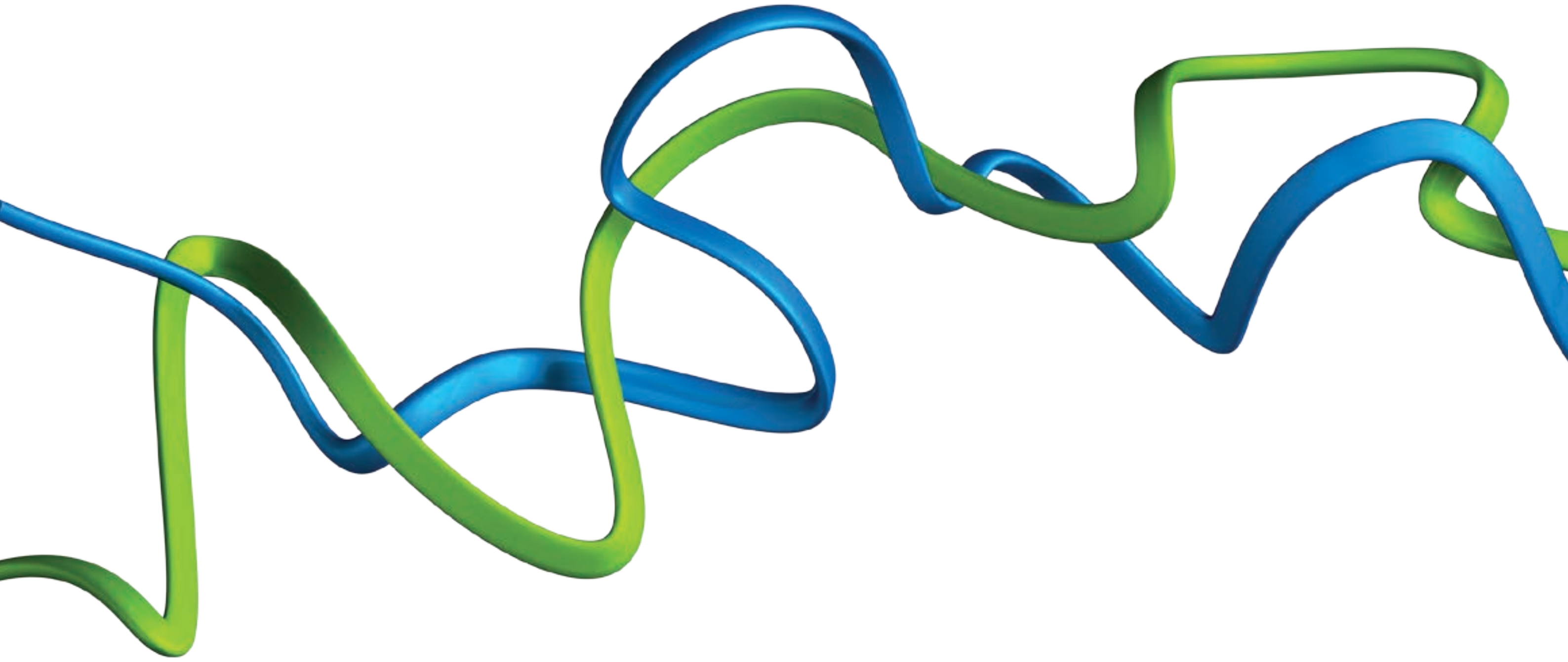
Harnessing the expertise, energy and capacity of the profession to provide strategic direction for engineering and collaborate on solutions to engineering grand challenges.



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