

Greater London Authority

Improved decision-making for
infrastructure resilience in London

Final report

V3 October 2020



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1. Introduction

London depends on its infrastructure to function and thrive. It is therefore crucial that infrastructure is able to remain resilient and prepared for future challenges such as climate change, growing population, ageing assets, and increased urban density.

London's infrastructure networks are increasingly complex and interconnected. These systems rely on digital, electrical and physical connections to function properly. A disruption to one network can produce far-reaching and unanticipated cascading effects. A robust understanding of interdependencies can help identify those sections of the network with biggest impact and, in turn, inform planning and investment decisions.

The London Resilience Strategy [1] identifies innovative use of data and information as a key enabler to improve infrastructure resilience through better decision-making.

Arup and UCL were commissioned by the Greater London Authority (GLA) to examine how they can support infrastructure providers to improve their ability to prioritise investment decisions that will have the most significant impact on building the resilience of London's infrastructure systems now and in the future.

Study Scope

This project set out to examine requirements and barriers to improving decision-making for resilience in London's infrastructure, with a particular emphasis on how data and information are used to make decisions in the economic infrastructure sectors, and how data

innovation can be harnessed to facilitate more effective action. In particular, it sought to establish:

- how infrastructure providers currently consider resilience in planning and investment decisions;
- how interdependencies are currently assessed and managed, and whether they are integrated in decision-making;
- where gaps in information and skills exist and what the barriers are;
- a range of potential solutions to can help fill the identified gaps; and
- a prioritised set of tangible actions can be put in place to support London's infrastructure providers in making better decisions for resilience.

This study focused on economic infrastructure decision-making for resilience. Emergency planning was excluded from the scope. Economic infrastructure is defined as energy, transport, water and wastewater (drainage and sewerage), waste, flood risk management and digital communications [2].

In terms of the planning cycle, a 5-year horizon is commonly used when planning infrastructure in London. However, this study has considered the longer horizon between now and 2050 to align with the London City Resilience Strategy [1].

The definition of resilience given in the London Resilience Strategy (on the right) has been adopted for this study.



“Resilience is the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and thrive no matter what kinds of chronic stresses and acute shocks they experience.”

[1] https://www.london.gov.uk/sites/default/files/london_city_resilience_strategy_2020_digital.pdf

[2] As defined in: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/585374/NIC_framework_document_web.pdf

2. Our approach

This study used ‘mixed methods’ research [3] combined with a user-centred methodology. Our approach consisted of the following stages:

- 1. Understanding current resilience challenges** – this stage set out to understand how infrastructure providers currently consider resilience in asset maintenance and investment decisions, their current understanding of interdependencies, and to identify barriers and gaps in data, information and knowledge. Stakeholder engagement formed an essential activity within this stage and throughout the project. It comprised a [stakeholder survey](#), alongside [1-to-1 interviews](#), to understand current challenges for considering resilience in infrastructure decision-making (the ‘resilience challenges’).
- 2. User story development and prioritisation** – from analysis of the interviews and survey, we developed a ‘[long list](#)’ of [user stories](#) that capture requirements of the infrastructure providers in a simple and accessible way. A multi-criteria analysis was used to shortlist [prioritised user stories](#) in the [stakeholder workshop](#).
- 3. Solution development** – Based on the prioritised user stories, this stage looked at developing [potential solutions](#) to the identified resilience challenges, informed by findings from the [stakeholder workshop](#), alongside [case study research](#).
- 4. Recommended actions** – this stage presents a [prioritised set of actions](#) that the GLA could take to support the infrastructure providers to address the identified resilience challenges and to improve their decision-making for resilience.

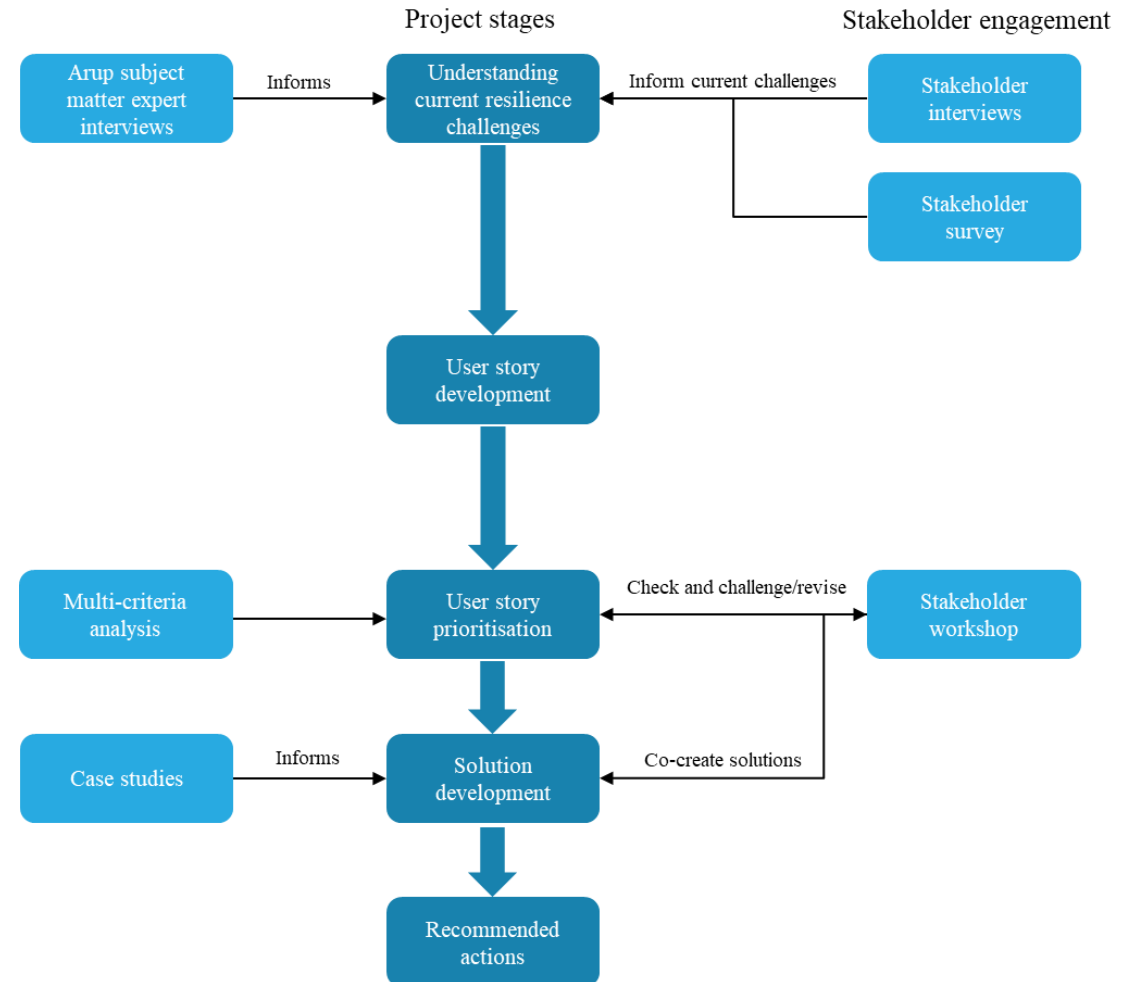





Figure 1: Overview of project approach used to identify of prioritised user stories and potential solutions co-created with the GLA’s infrastructure stakeholders.

3. Understanding the current resilience challenges

Stakeholder engagement

Engagement with the GLA's infrastructure stakeholders formed an essential part of this project. Working with stakeholders, we identified the challenges infrastructure providers currently face in including resilience in decision-making, understood their requirements and co-created potential solutions for the GLA to develop going forward.

We engaged stakeholders using the following methods:

-  1-to-1 interviews
-  Stakeholder survey (see Appendix A for results)
-  Online workshop (see Appendix B for workshop slides and report)

We supplemented external stakeholder engagement with interviews with 11 Arup subject matter experts across each of the respective infrastructure sectors.

The organisations that participated in the stakeholder engagement activities are shown in Figure 2. 17 individuals responded to the survey, 5 1-to-1 interviews were undertaken and 16 attended the online workshop.

The interviews and survey helped us to initially understand how resilience was considered in decision-making within their organisations across strategic, tactical and operational planning levels. This is explored in more detail in Section 4, p13.

Interviewees and consultees were also asked about their

organisation's interactions with other infrastructure providers, specifically which ones they currently interface with and how regularly, as well as what data they share. Additionally, we asked what other infrastructure providers they would like to interact with, what data access would be required, the current barriers to achieving this and their views on potential solutions (see Section 3, p7-8).

We investigated how interdependencies across infrastructure sectors were considered and what the barriers to including them in decision-making were (see Section 3, p9).

We gathered thoughts on how to strengthen the business case for resilience and whether it would be possible to be more creative with funding models (see Section 3, p10).

Findings from the interviews and survey were developed into user stories, which are discussed in Section 4.

A detailed analysis of all stakeholder engagement activities undertaken by this study is included in Appendix C.



Figure 2: Organisations that participated in stakeholder engagement activities



3. Understanding current resilience challenges (cont.)

Key themes

From an initial analysis of stakeholder interviews and survey, a number of key themes were drawn out (see below). These key themes were used to extract and categorise user stories for discussion in the stakeholder workshop. The key themes narratives presented in the following pages were informed by all stakeholder engagement activities (1-to-1 interviews, survey and workshop) and highlight data and information needs, barriers and capacity gaps.

Understanding of asset health/criticality

e.g. understanding of asset health across sectors; criticality of own and others assets; criticality methodologies.

Local growth and planning information

e.g. early engagement with developers; understanding of local growth strategies and implications for infrastructure investment; cross-sector infrastructure investment plans.

Coordinated planning and investment opportunities

e.g. coordinated street works; sharing of resources (maintenance and assets).

Data sharing for resilience investments

e.g. innovative use of data; Internet of Things and sensor technology.

Infrastructure interdependencies

e.g. understanding of how own system depends on others; identifying potential cascading impacts.

Assessment of resilience benefits

e.g. considering the cost and demonstrating the benefits of resilience schemes to build business cases.



3. Understanding current resilience challenges (cont.)

Understanding of asset health/criticality

Most stakeholders highlighted that an understanding of asset health and criticality across sectors would be valuable to their organisations. One said that it “[would] allow me to understand their asset health and influence them or amend my asset resilience”. Some organisations would also like to use this information to improve their own approaches to criticality assessment. Moreover, this could represent an opportunity to look for and prioritise shared maintenance opportunities.

Particular barriers to wider sharing of this data included security concerns, particularly for those assets classed as Critical National Infrastructure. Discussion around a consistent criticality metric questioned whether it is possible, or indeed helpful, given the existing differences between assets and sectors.

Local growth and planning information

There was agreement among stakeholders that access to local growth and planning information is valuable to organisations, and that it would contribute to improving the resilience of their systems. One said that this is “*absolutely vital to inform any future investment*”. A number of interviewees stated that it would be particularly beneficial to understand the cumulative impact of smaller scale developments. Moreover, having sight of early planning applications would allow for early conversations to co-develop potential solutions and ensure more resilient infrastructure and communities.

Stakeholders also suggested that they would like information on planning applications or schemes proposed by other infrastructure providers, even if not approved, as this may also present early opportunities to co-create potential solutions or share resources. Several interviewees said that this is currently difficult for their organisation to do. 65% of survey respondents said that data availability was a barrier to including infrastructure interdependency assessment into decision-making, with one in particular naming the “*willingness of other organisations to share data*”.



3. Understanding current resilience challenges (cont.)

Coordinated planning and investment opportunities

Overall, our survey and workshop showed that coordinated planning and investments - such as coordinated street works, sharing of maintenance resources or co-funded improvement schemes - is generally not something that most organisations are doing as part of business as usual. This can be due to a reluctance to share, for example, financial or other sensitive information. Some stakeholders suggested that this is being done within centralised and local planning processes, and the development of any potential solutions needed to ensure that this work is not duplicated or disconnected. Others stated that the majority of coordination happens through street works activity at the operational planning level; although this is not consistent.

Most agreed that coordinated investments would be valuable to their organisation. For example, an individual stated that planned works around flood defences could also protect their own and other asset owners sites.

Another individual said that a “*cost sharing mechanism*” is required to help to coordinate investment opportunities with other asset owners who have a stake to ensure that investments deliver resilience outcomes for all parties involved. With another stating that it “*would also be useful for the economic regulators to understand this interaction as funding decisions in one area could impact the resilience in another sector*”. We are aware that the GLA is working towards this, through its Infrastructure Coordination Service and the development of a Framework Alliance Contract (FAC) to facilitate easier coordination across organisations. These findings therefore reinforce the need for such mechanisms.

Data sharing for resilience investments

Some suggested that data sharing is already in place, with the [Infrastructure Mapping Application](#) (IMA) and associated agreements. The IMA is an interactive web-based mapping tool developed by the GLA that displays growth and development data, future infrastructure investment data, and contextual information relating to construction and infrastructure in Greater London. However, apart from the IMA, data sharing is typically *ad-hoc* and requires bespoke agreements. Data and information required for resilience investments ranges from high level information,

e.g. approaches to asset criticality and strategic investment plans, down to detailed asset data and information e.g. asset health and condition, pinch points or interfaces with other networks or providers.

Most stakeholders agreed that data sharing would be valuable to their organisation, particularly, as one interviewee stated, “*lots of assumptions are made during planning*”. Another individual stated, “*access to a wider source of data will allow for a more robust decision-making framework for prioritising investment across our asset portfolio*”. Importantly, a number of individuals stated that this wouldn’t be difficult for organisations to do, and therefore presents an opportunity to be a quick win. One respondent suggested that representative bodies e.g. Energy Networks Association for energy, Water UK and EC-RRG for digital communications could act as integrators. However, these are siloed within their sectors.

Several interviewees highlighted the potential for the innovative use of data and information to build and support resilience. For example, one discussed the application of mobile data for footfall assessment, and another discussed the use of Internet of Things and asset sensor technology for monitoring asset health and condition (see Figure 4 below).

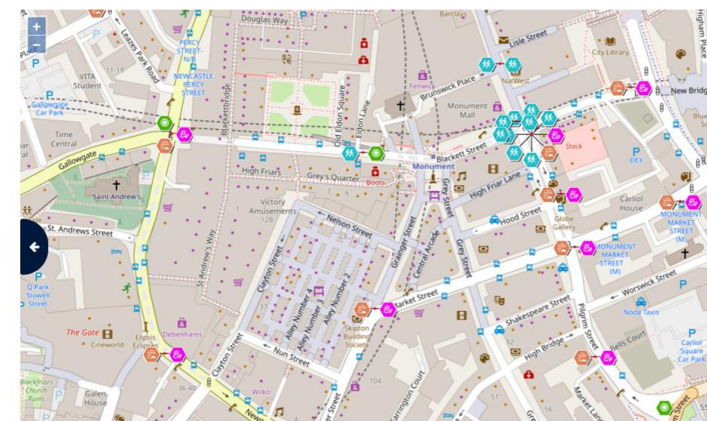


Figure 4: Example of Urban Observatory sensor deployment interface, Newcastle upon Tyne (see Appendix F for full case study)



3. Understanding current resilience challenges (cont.)

Infrastructure interdependencies

Understanding how interdependencies between infrastructure systems are considered in decision-making was a key part of this study. The majority of survey respondents suggested that this is something that is considered in their organisation and they were aware of the importance of interdependencies to prevent/mitigate cascading impacts. Where interdependencies are considered, a number of individuals stated that this is typically through emergency planning work. Conversely, the workshop identified that this isn't something that their organisations typically do. This contradiction highlights that there is room for further work in this area.

One individual stated that *“by considering interdependence in greater depth overall infrastructure resilience would be better planned”*. Importantly, another said that this would also *“inspire collaboration and innovation and avoid duplicated investment”* while another said *“better awareness of our own and other's likely pinch points would be useful. If only as a means of reassurance”*.

Through the stakeholder survey, a number of barriers to understanding and managing infrastructure interdependencies were identified (see Figure 3). Data availability was identified as a key barrier to understanding and managing infrastructure interdependencies (65% of respondents). Knowledge sharing (53%), security and confidentiality (47%), and regulatory requirements (41%) were also recognised as other key barriers. The survey showed that a significant number of respondents (71%) had not attended previous training workshops on the consideration of interdependencies. Importantly, an interviewee from the energy sector stated that the regulator is needed in discussions around consideration of interdependencies.

We also asked stakeholders about whether Covid-19 had revealed any new interdependencies within their sector. Nearly half of respondents said 'Yes' it had. Examples included increased reliance on digital communications to operate their businesses remotely (including home working) and impacts on resources required to maintain and operate infrastructure networks.

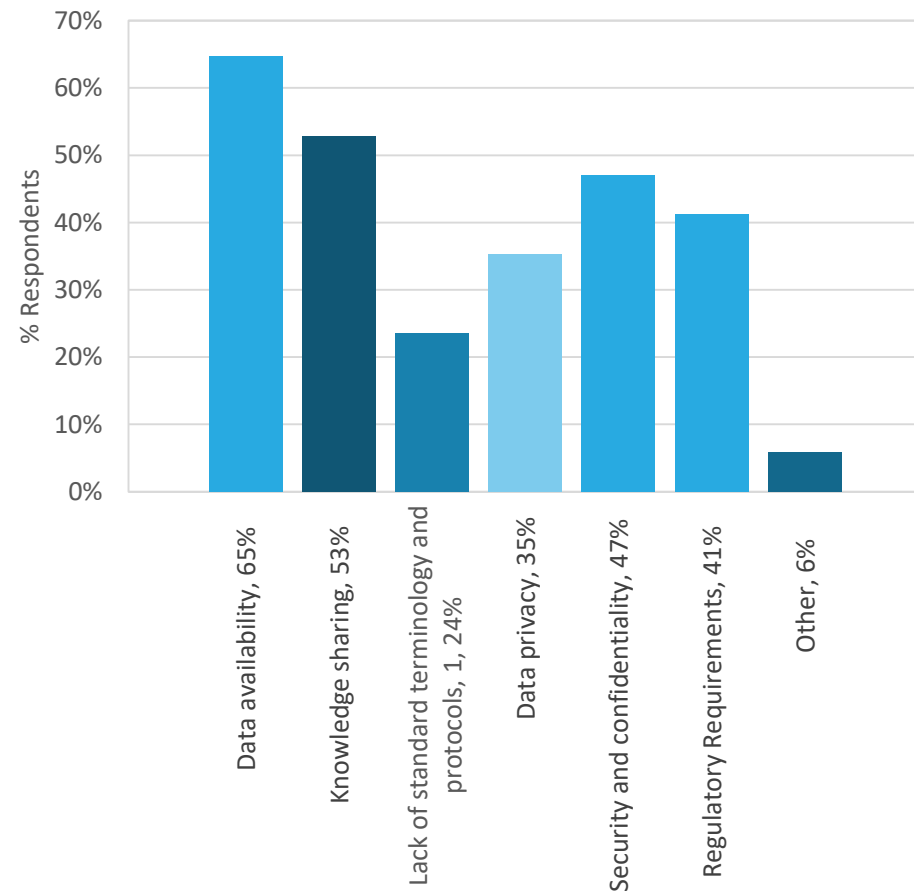


Figure 3: Barriers to consideration of interdependencies in infrastructure decision-making (source: stakeholder survey)



3. Understanding current resilience challenges (cont.)

Assessment of resilience benefits

The measurement of resilience benefits of infrastructure schemes was raised across several interviews. Benefits assessments are how organisations measure the expected impact of an infrastructure scheme. Resilience benefits are those delivered by resilience-led schemes. Benefits are traditionally assessed based on financial returns but interviewees highlighted that their companies now typically consider the wider benefits that schemes deliver. Well-being of infrastructure users, air quality and wider socio-economic and environmental impacts (co-benefits or indirect benefits) were mentioned as examples in the interviews.

Approaches to assessment of resilience benefits that transcend traditional cost-benefit analysis are not mature and are still being developed. For example, the Environment Agency is pioneering a new approach to benefits in their upcoming strategy (due for publication in 2020) that will provide further information on wider benefits of flood defence schemes. These will include social benefits, for example reduced mental health issues associated with reduced flooding of homes.

The water sector is probably most advanced here. An interviewee stated that they are interested in “*insights into whole catchment benefits*”, which indicates increased adoption of a system approach rather than focussing on specific assets and schemes. However, interviewees from the gas sector also expressed a desire to assess the wider benefits of resilience schemes and collaborative opportunities to the whole energy sector and to its customers.

Once again, regulatory issues were discussed, with one workshop attendee stating “*regulatory constraints mean that it is hard to spend significant money on investments which do not help improve our company performance commitments or reduce financial risk*”. However, another individual stated that considering wider benefits of investments in resilience can “*help justify funding requirements to regulators*”. This highlights that building a business case for resilience schemes is currently challenging and requires support and guidance.



Source: <https://www.pexels.com/photo/grayscale-photography-of-bridge-during-nighttime-2564153/>



4. User Story Development and Prioritisation

What is a user story?

A user story, typically used in software development, captures the description of a software feature from an end-user perspective in non-technical language. It describes the type of user, what they want and why (see Figure 5). This creates a simplified description of the requirement, and provides the development team with context to understand the value that is sought from the proposed application. In this case we are considering a wide range of potential solutions for integrating resilience considerations into decision-making that range from digital tools to capacity building or policy change.

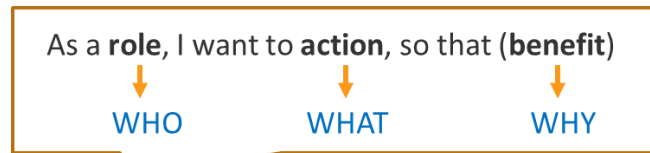


Figure 5: User story format

The user story format ensures a consistent approach, focused on understanding the motivations, pain-points, and goals of users. It is key to making sure that any solutions considered are grounded in and respond to the needs of the infrastructure providers, and ultimately leads to prioritisation of investment towards the interventions that will have the most significant impact on building the resilience of London’s infrastructure.

Development of user story ‘long list’

An initial ‘long list’ of user stories (see Appendix D) was developed based on analysis of the 1-to-1 interviews and survey. They were analysed for mentions of actions and resultant benefits related to infrastructure interdependencies and resilience. 49 user stories were identified.

The software platform Trello was chosen to present the user stories due to the ability to tag and aid prioritisation (Figure 6); see [link](#) to the Trello

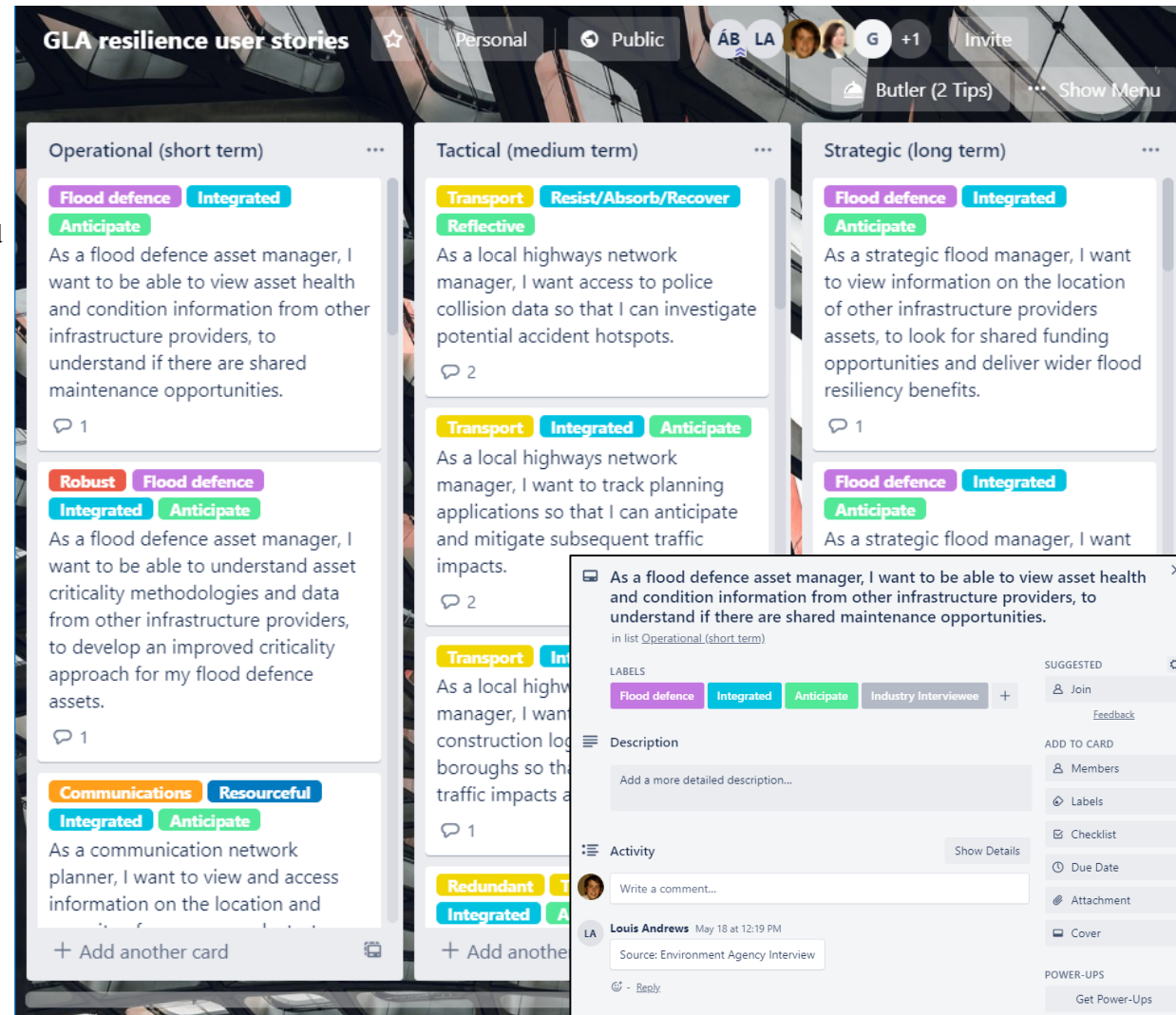


Figure 6: Extract of Trello board of ‘long list’ of user stories. Inset: an example of individual user story with tags and source shown.



4. User Story Development and Prioritisation (cont.)

Analysis of the user stories was undertaken in order to better understand the breadth of information gathered, gain insights and prioritise them for further exploration in the stakeholder workshop. User stories were categorised according to:

- what infrastructure sector they were applicable to
- how they could be related to resilience
- what level of planning they were relevant to (see next page)
- which key theme (see Section 3) the content related to.

Infrastructure sector

User stories were tagged by the economic infrastructure sector they apply to, shown in Figure 7. Initially user stories were identified to address a concern within a sector, however, cross-sector applicability was also considered and some user stories are tagged with multiple sectors. Results highlight an under-representation of the digital communication sector.

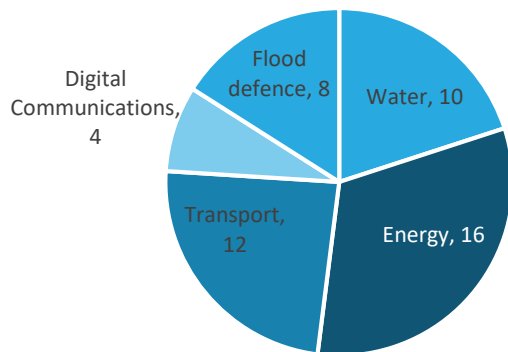


Figure 7: User stories categorised by sector.

Resilience

Recognising that implementing some of the user stories could simply be considered to be good planning according to standard practice, it was important to highlight how they can also contribute to resilience. Therefore, ‘resilience lenses’ were applied to the user stories by considering their relationship to different resilience phases and qualities, as explained below.

Resilience phases were derived from the National Infrastructure Commission’s Resilience Framework [4], and include: Anticipate; Resist / Absorb / Recover; and Adapt / Transform. Some of the stories were tagged with more than one phase, but the majority were in the anticipate category, as shown in Figure 8. This was not surprising as the project focused on decision-making outside of emergencies.

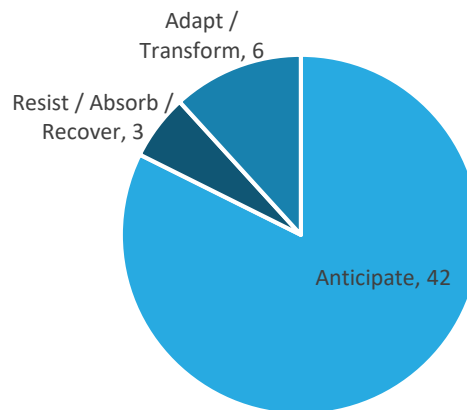


Figure 8: User stories categorised by resilience phase.

The London City Resilience Strategy identifies 7 resilience qualities that a resilient system should possess, ranging from robust to inclusive and integrated. These were tagged against the user stories. Figure 9 shows the distribution of the user stories by resilience quality. This shows the majority of user stories are associated with the ‘integrated’, ‘inclusive’ and ‘robust’ qualities, while there was not much consideration of ‘adaptive’ or ‘reflective’ qualities. Adaptive approaches are flexible by design and are able to adopt alternative options in response to changing circumstances. Reflective approaches learn from past experiences to inform future decisions. The analysis indicate that there may be capacity gap in being able to develop and deploy adaptive and reflective approaches to resilience.

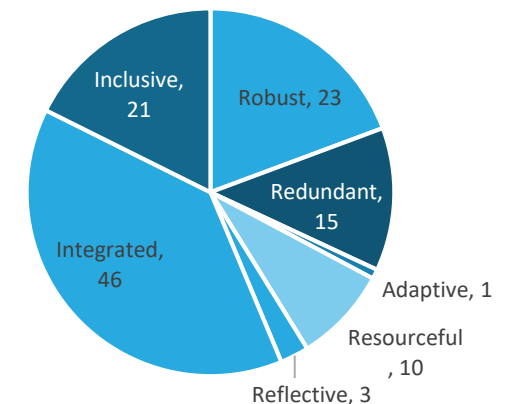


Figure 9: Distribution of resilience qualities across long list of user stories

[4] <https://www.nic.org.uk/wp-content/uploads/Anticipate-React-Recover-28-May-2020.pdf>



4. User Story Development and Prioritisation (cont.)

Planning level

The user stories were also categorised in terms of whether they related to operational, tactical or strategic planning (see Figure 10). These levels are widely recognised in the asset management discipline and are defined as follows:

- Strategic planning encompasses a high-level overview of the entire business, its vision, objectives and values. This is usually long-term e.g. more than 5 years.
- Tactical planning describes the tactics that the organization plans to use to achieve the ambitions described in the strategic plan. This is usually mid-term e.g. less than 5 years.
- Operational planning describes the day-to-day running of the company.

Regarding the specific roles of the stakeholders interviewed, the majority were associated with 'tactical' decision-making. This included a range of individual roles, from data managers to investment planning managers.

There were 12 operational, 16 tactical and 21 strategic user stories. This may indicate that the stakeholders engaged with should be broadened out to include more from the operational side in future stakeholder engagement.

Responses to the survey highlighted the differences in consideration of interdependencies at the different levels of decision making. Results showed a very positive response for organisation's operational planning, with a lower level for tactical and strategic planning. These results suggest that, while operational planning consistently indicates a level of maturity, there seems to be a need for promoting a consistent approach to tactical and strategic decision-making across the organisations.

This consistent approach will enable a line of sight across these three levels to be maintained, so that strategic aspirations for resilience are

translated to tactical and operational decision-making. Equally, operational constraints and opportunities should be communicated upwards to inform tactical and strategic considerations.

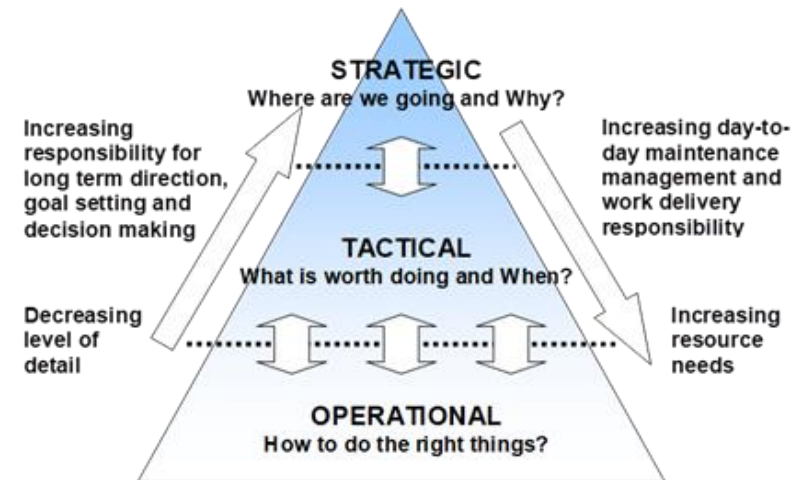


Figure 10 : Relationship between operational, tactical and strategic planning. Source: [International Road Federation](#) (after ISO55000 Asset Management).



4. User Story Development and Prioritisation (cont.)

User story prioritisation

From the initial ‘long list’ of user stories, a prioritisation exercise was undertaken to identify a prioritised list of user stories. These prioritised user stories were then used for focused discussion during the stakeholder workshop.

This initial prioritisation exercise was informed by three elements:

- Clustering and rationalisation to avoid duplication, i.e. user stories that were very similar were clustered.
- Cross-sectoral relevance, i.e. the extent to which the user story takes into account interdependencies and has cross-sectoral impact.
- Alignment with the key themes, as outlined in Section 3.

User stories with the maximum relevance across sectors were prioritised. In addition, user stories that represented the key themes were also chosen, even if they did not have full relevance in all sectors, but had aspects of the key themes that were highlighted by several interviewees.

8 prioritised user stories were identified and are presented in the table to the right with the relevant themes and sectors. The stories identified included two from the flood defence sector, four cross-sector and two from the energy sector. Although some originated in one sector, they were chosen due to their relevance across several sectors and how they responded to the key themes, e.g. user story no. 8 which is from the energy sector but directly covers benefits assessment.

These user stories were then brought forward for consideration in the workshop, as discussed overleaf.

<i>Prioritised User Story</i>	<i>Sector</i>	<i>Key Theme</i>
1. <i>As a flood defence asset manager, I want to be able to understand asset criticality methodologies and data from other infrastructure providers, to develop an improved criticality approach for my flood defence assets.</i>	Flood defence	Understanding of asset health/criticality
2. <i>As a flood defence asset manager, I want to be able to view asset health and condition information from other infrastructure providers, to understand if there are shared maintenance opportunities.</i>	Flood defence	Understanding of asset health/criticality
3. <i>As an infrastructure operator/developer/asset manager I want to assess the cumulative impact of smaller scale developments that are not systematically logged so that I can flag potential risks to infrastructure capacity & resilience before they occur</i>	Cross-sector	Local growth and planning information
4. <i>As a power network planner, I want to know or estimate the locations of current or future electric vehicle charging points so that I can ensure capacity can meet the additional demand.</i>	Energy	Coordinated investment opportunities
5. <i>As an infrastructure owner/developer/manager I want to improve the reliability and speed of access to information to streamline the way in which information is shared and used.</i>	Cross-sector	Data sharing for resilience investments
6. <i>As an operations manager, I will be able to understand where I have dependencies with other infrastructure providers to facilitate conversations around ensuring their resilience.</i>	Cross-sector	Infrastructure interdependencies
7. <i>As an infrastructure planner, I want to view deprivation and inequality data so that I can assess the impact of investment planning on socio-economics.</i>	Cross-sector	Benefits assessment
8. <i>As a gas distribution network manager, I want to consider the cost and demonstrate the benefits of resilience schemes so that the best value for customers can be sought.</i>	Energy	Benefits assessment



4. User Story Development and Prioritisation (cont.)

Multi-criteria analysis

A multi-criteria analysis (MCA) framework was developed based on Likert scale, adapted from Pescaroli et al [5]. It was used with the aim to better understand and further prioritise user stories at the stakeholder workshop. The following factors were scored on a five-point scale:

- **Current state** i.e. whether this user story is already being implemented within the organisation/sector.
- **Organisational value** i.e. the benefits to the organisation of implementing this user story.
- **Difficulty** i.e. whether this user story is difficult for organisation/sector to implement
- **Resilience value** i.e. the benefits to system resilience of implementing this user story

The quantitative scores of each factor were used to analyse the user stories in terms of capacity gaps, resilience value, difficulty experienced by users and benefits delivered to them.

Stakeholder workshop - prioritisation

During the workshop, we played back to attendees the key themes (Section 3) and user stories (Section 4) that had emerged from the analysis of the interviews (external stakeholders and Arup subject matter experts) and survey.

Attendees at the stakeholder workshop were presented with 8 prioritised user stories. This provided an opportunity for stakeholders to check and challenge the

user stories being put forward. We then asked workshop attendees to score the user stories according to the MCA framework.

There was generally a positive response from attendees when it came to the '**current state**' criterion, i.e. whether the user story was already being implemented within their organisations. The average score for 'current state' across all user stories was 2.7/5, with none falling below 2.3. This indicates a reasonably high level of perceived maturity, also found in the online survey (see Appendix C), that forms a strong basis from which to build infrastructure resilience in London.

The highest scoring user stories according to the '**organisational value**' criterion (4.4/5) were '*As a flood defence asset manager, I want to be able to understand asset criticality methodologies and data from other infrastructure providers, to develop an improved criticality approach for my flood defence assets*' in addition to '*As an infrastructure planner, I want to view deprivation and inequality data so that I can assess the impact of investment planning on socio-economics.*' Both were also given a high resilience value (4.5/6), showing that they are of value to the organisations as well as to the overall system.

High '**difficulty**' user stories included '*As an infrastructure operator/developer/asset manager I want to assess the cumulative impact of smaller scale developments that are not systematically logged so that I can flag potential risks to infrastructure capacity & resilience before they occur*' in addition to '*As a flood*

defence asset manager, I want to be able to view asset health and condition information from other infrastructure providers, to understand if there are shared maintenance opportunities', although the latter is being implemented in the Infrastructure Mapping Application already. The latter was also highlighted as being of high resilience value (4.3/5), so this project underlines the importance of the IMA work.

Workshop attendees gave the highest '**resilience value**' and lowest '**difficulty**' to '*As a power network planner, I want to know or estimate the locations of current or future electric vehicle charging points so that I can ensure capacity can meet the additional demand.*' This shows it could be a high impact, low effort option.

The criteria scores for the prioritised user stories are presented in full in Appendix E, and there is further analysis of the prioritisation in Section 2.1 of Appendix C.



4. User Story Development and Prioritisation (cont.)

Stakeholder workshop – detailed story discussion

The second half of the workshop was used to discuss 3 user stories in more detail and to co-create potential solutions, alongside eliciting other key stakeholder priorities that have been incorporated in the key theme narratives (Section 3) and have informed the conclusions and recommendations (Sections 6 and 7).

The selection of the 3 user stories was partially informed by the level of discussion that each theme/user story produced, and the survey and interviews undertaken.

The 3 user stories discussed in more detail were:

- *As a flood defence asset manager, I want to be able to understand asset criticality methodologies and data from other infrastructure providers, to develop an improved criticality approach for my flood defence assets.*
- *As an operations manager, I want to be able to understand where I have dependencies with other infrastructure providers to facilitate conversations around ensuring their resilience.*
- *As a gas distribution network manager, I want to consider the cost and demonstrate the benefits of resilience schemes so that the best value for customers can be sought.*

Barriers to implementing these user stories raised by stakeholders included differences in use of terminology related to resilience, concerns about data security and

lack of understanding of the data requirements as well as availability of funding, all of which were also found in the stakeholder survey (see Appendix C).

The discussion also covered potential solutions for these user stories. The next section overleaf reviews the potential solutions that are available to help the GLA respond to the prioritised user stories identified by this study.



Source: © Arup



5. Solution development

Potential solutions

This section provides a summary of the potential solutions to the prioritised user stories. Analysis of the results of stakeholder engagement activities and the user stories development indicated that potential solutions sought by the infrastructure providers broadly fall into 4 categories: supplementing data gaps, capacity building, development of digital products and policy intervention. These are briefly described below.

Supplementing Data Gaps (e.g. providing new data and information)

Supplementing data gaps came up repeatedly in stakeholder engagement e.g. application of mobile data to help understand demand for rail services and station upgrades. Or the need to get data on security of supply needs for other infrastructure such as reliance of water treatment plants on electricity networks.

Capacity building (e.g. training and workshops)

Capacity building can include workshops or alternatively training focused on a specific aspect e.g. how to use the IMA for investment decision-making for resilience, or how to manage cross-sector interdependencies in practice.

Development of digital products (e.g. further development of Infrastructure Mapping Application)

Development of digital products is a solution for a specific need that goes beyond a data gap, although it typically requires data inputs. A lot of data may already exist, but a digital solution is required to convert this into usable information. An example would be

converting data from the London Development Database into a representation of the impact of development on gas network capacity, for example.

Policy intervention (e.g. mandated resilience and interdependencies assessments)

Government and regulator lobbying is associated with where policy change has been identified by the GLA's stakeholders, but where changes do not fall under the GLA's jurisdiction. This could be for example, lobbying the Government to set resilience standards (as recommended in the National Infrastructure Commission's resilience study).

Stakeholder engagement consistently confirmed a mandate for the GLA to help provide some of these solutions, e.g. a workshop participant that said: *"The GLA would be the sensible coordinator or a body of that sort [to help bring together regulators and infrastructure owner/operators]."*

Case studies

Solutions were also informed by the case study research that identified examples of best practice in resilience and interdependencies assessment, including use of innovative and/or digital technologies. The case studies have cross-sector applicability and can provide inspiration in developing solutions.

Full case studies are included in Appendix F. Two of these that were particularly relevant to this study, EDGe\$ and GRRASP, are presented in Box 1 and 2. Direct engagement with the tool developers was arranged as part of this project to give insight into relevance for the GLA.

Box 1: Economic Decision Guide Software (EDGe\$)



EDGe\$, developed by the US National Institute of Standards and Technology, is a tool that helps to identify and compare the relevant present and future resilience costs and benefits associated with new capital investment alternatives versus maintaining a community's status-quo. Interdependencies are considered within the use of this tool through the quantification of externalities, external benefits and uncertainties. The tool guides the user to consider the cash costs of externalities, whether they are positive or negative, the parties effected etc. This information is fed into the decision-making model to determine the ultimate cost-benefit scores.

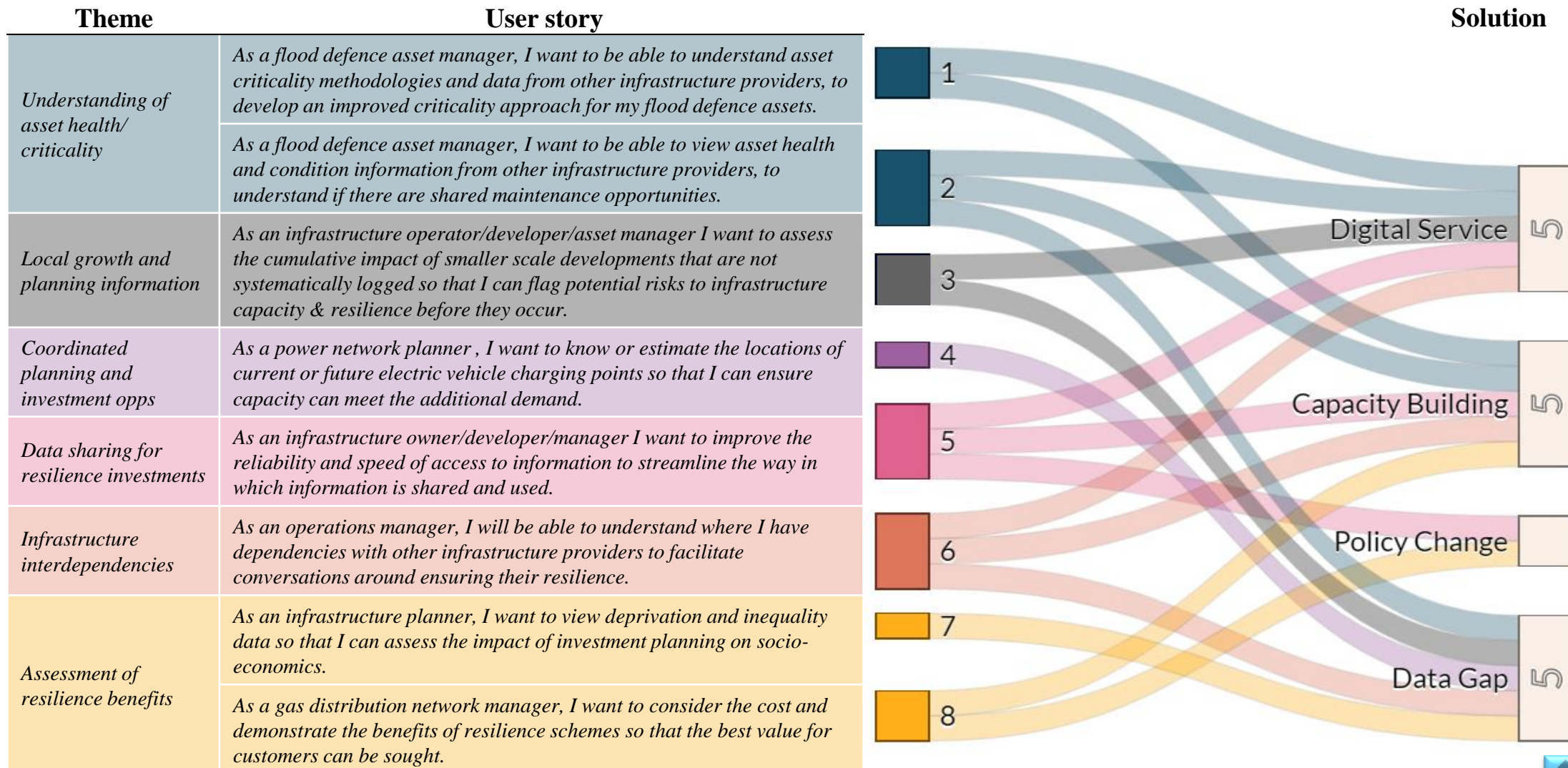
Box 2: Geospatial Risk and Resilience Assessment Platform (GRRASP)



GRRASP, developed by the European Commission Joint Research Centre, is an open-source tool combining geospatial and computational technologies to analyse critical infrastructure systems. GRRASP can be used to perform network analysis to evaluate metrics related to the structural characteristics of infrastructure systems. These include metrics developed uniquely for GRRASP: criticality and vulnerability. The tool incorporates analysis of the economic impact of a disruption.

5. Solution development

This page shows the user stories prioritised from the ‘long list’ of user stories, colour coded by key theme. These are linked to types of potential solutions. The attribution to solution categories are based on (a) workshop feedback and (b) interpretation by Arup/UCL. Some of the user stories have multiple potential solutions.



6. Conclusions

This project has examined requirements and barriers to improving decision-making for resilience in London's economic infrastructure, with a particular emphasis on how data and information are used to make decisions in the economic infrastructure sectors, and how data innovation can be harnessed to facilitate more effective action.

This research has combined a 'mixed methods' stakeholder engagement with a user-centred approach that focussed on the needs of the users and challenges they face in considering resilience as part of their decision-making. Engagement with the GLA's infrastructure stakeholders through interviews, a survey and a workshop formed an essential part of this project. The user stories development and analysis has helped articulate stakeholder challenges in a simple and accessible way and provided an insight into gaps, barriers and opportunities.

6 key themes were identified and narratives were crafted using results from all the stakeholder engagement activities (1-to-1 interviews, survey and workshop), highlighting data and information needs, barriers and capacity gaps.

8 prioritised user stories were identified as most representative of the key themes and they were further prioritised and used to co-create solutions in the stakeholder workshop.

The combined results of stakeholder engagement and user stories development strongly indicate a call for action to improve the way resilience is considered in

infrastructure decision-making.

Potential solutions and interventions identified by this study broadly fall into 4 categories: supplementing data gaps, capacity building, development of digital products and policy intervention. A prioritised set of recommendations is presented in Section 7.

Key findings are summarised below.

Resilience definition and approaches

The research found a significant level of maturity in the consideration of resilience in decision-making within organisations and sectors. This is a positive finding because it indicates that there is a strong basis from which to build infrastructure resilience in London. However, there were variations in the approaches across companies and sectors and in how resilience is considered across decision-making levels. While operational planning consistently indicates a level of maturity, there seems to be a need to ensuring that there is a line of sight for resilience across tactical and strategic decision-making across the organisations.

In addition, our analysis of the user stories indicated that there may be capacity gap in being able to develop and deploy adaptive and reflective approaches to resilience.

While a lack of common understanding and framework for resilience is a recognised issue in the infrastructure sector, there is need to ensure that the strategic vision and desired outcomes for London's resilient infrastructure systems are understood and embraced by infrastructure providers (see prioritised user story #1). This requires a cross-sector systemic approach to

resilience that should be developed under the GLA's leadership in collaboration with stakeholders.

Consideration of interdependencies

Understanding how interdependencies between infrastructure systems are considered in decision-making was a key part of this study. Stakeholder survey results found that interdependencies are being considered by organisations, but to a lesser extent in tactical and strategic planning levels, even though these areas were identified as those that would benefit the most.

Conversely, the workshop identified that this isn't something that their organisations typically do. This contradiction highlights that there is room for further work in this area. In addition, a significant number of survey respondents had not attended previous training workshops on the consideration of interdependencies.

Workshop attendees agreed on the importance and value of identifying interdependencies with other providers to facilitate conversations around ensuring their resilience (see prioritised user story #5).

However, data availability and knowledge sharing were highlighted as key barriers to understanding and managing interdependencies.

There is an opportunity for the GLA to take an active role in leading the way in this area. This could be done through targeted actions to facilitate data, information and knowledge sharing, i.e. capacity building/training activities and better provision of data and information (see overleaf and Section 7).



6. Conclusions (cont.)

Importance of data, information and knowledge sharing

Data, information and knowledge sharing were highlighted as key enablers for improved decision-making for resilience (see prioritised user story #3). Data and information sharing is already occurring through use of the IMA, although findings suggest that more could be done to improve awareness of the IMA among London's infrastructure providers. The types of information that stakeholders indicated as useful/desirable are asset criticality, condition and health, future EV charging points, planning applications for small scale developments, deprivation and inequality data (see prioritised user stories #1, 2, 4, 3 and 7, respectively).

Barriers to knowledge sharing include security and confidentiality. Results from stakeholder engagement activities consistently provide a clear mandate for the GLA to be the trusted convener and provide a neutral environment for data, information and knowledge sharing. Improved provision of data and information and will result in increased used of the IMA, leading to a more consistent and coordinated approach to resilience decision-making and to prioritisation of investments that most benefit the overall resilience of London's infrastructure.

Making the case for resilience investments

Several stakeholders suggested that funding for cross-sector activities is difficult in the current regulatory regime. A question of “*who pays for providing*

resilience to others?” was posed. Often it is not affordable to put significant resources against such activities, as it would initially impact customer bills.

A ‘*cost-sharing*’ mechanism was recommended by one interviewee.

In addition, traditional cost-benefit analysis is not adequate for assessing benefits delivered by resilience-led schemes. Novel approaches are required to assess wider and indirect benefits (see prioritised user story #7 and 8).

The study confirmed that building a business case for resilience schemes is currently challenging and requires support and guidance.

Need for policy action

A number of stakeholders identified the need for the GLA to influence existing regulatory requirements that don't necessarily permit cross-sector collaboration as another key barrier. This conclusion provides further evidence for the need of the work that the GLA is already doing to ensure that the policy, regulatory and commercial frameworks are meeting Londoners' demands and the challenges faced by the infrastructure sector in meeting them. A coordinated set of policy interventions is needed to reach across sectors to a systems level, ultimately leading to improved resilience across London.

Some respondents suggested that encouragement from regulators and government could improve interdependency considerations in their day-to-day operations. Therefore, capacity building around

interdependencies assessment should be complemented by regulator lobbying, particularly within those sectors that are more heavily regulated (e.g. water and energy).

The recommendations emerging from the National Infrastructure Commission's [Resilience Study](#) may represent an opportunity for the GLA to leverage this to embed resilience and interdependency assessments more widely.

Identified research gaps and limitations

The project team identified gaps in the stakeholders engaged with in the current research.

The failure of economic infrastructure assets and systems can trigger cascading effects on other services. These services are also vital for the continuity of social functions, including healthcare, emergency services (both first response and councils), the financial institutions and large businesses. During crises such as the COVID-19 pandemic, the disruption of social functions can create secondary emergencies that are harder to control. These stakeholders are critical users of infrastructure and should be included in future conversations.

In addition, adaptation specialists and emergency / business continuity planners should be part of shaping the decision-making process for resilience. There is a need to create a bridge between the knowledge and expertise from emergency and business continuity planning with their understanding of cascading impacts and the long term planning / decision-making to deliver resilient infrastructure in the future.



7. Recommended actions

These six recommendations (R1 to R6) will enable the GLA to positively influence better decision-making for resilience. They were prepared through extensive stakeholder engagement and multi-criteria analysis described in this report.

R1. Convene interdependency workshops

The GLA infrastructure team should convene a series of workshops for infrastructure providers to identify tangible actions around proactive consideration of cross-sector interdependencies and resilience in decision-making. The strategic vision, desired outcomes and common terminology for London’s resilient infrastructure systems need to be communicated and understood across all sectors in the Greater London area. More work is required to better define data requirements for interdependency management and to identify security and confidentiality issues for data sharing, and there is a common need for this.

These workshops would differ from the one carried out for this project as it would build capacity around management of interdependencies *in practice* and also account for resilience benefits (see also R5) through targeted pilots using real data. This could include showcasing existing best practice examples (see Case Studies in Appendix F).

The long-term outcome of this would be a working group of tactical and strategic level infrastructure providers that meet regularly to share information, successes and failures. This working group would be a counterpart to the [Mayor’s London Infrastructure Group](#),

involving a lot of the same organisations but not at such as senior (C-suite) level.

The stakeholder survey identified convening workshops, training or capacity building as the most popular action for the GLA to take, as requested by the respondents. Results from this question are shown in Figure 13, with further analysis in Appendix C.

Convening these workshops will allow the GLA to take on the role of an independent body that promotes and facilitates the consideration of interdependencies in decision-making across London’s infrastructure sectors.

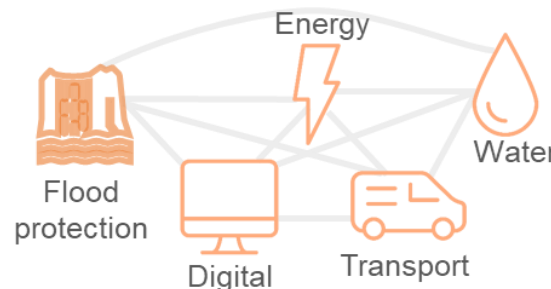


Figure 12: Infrastructure interdependencies

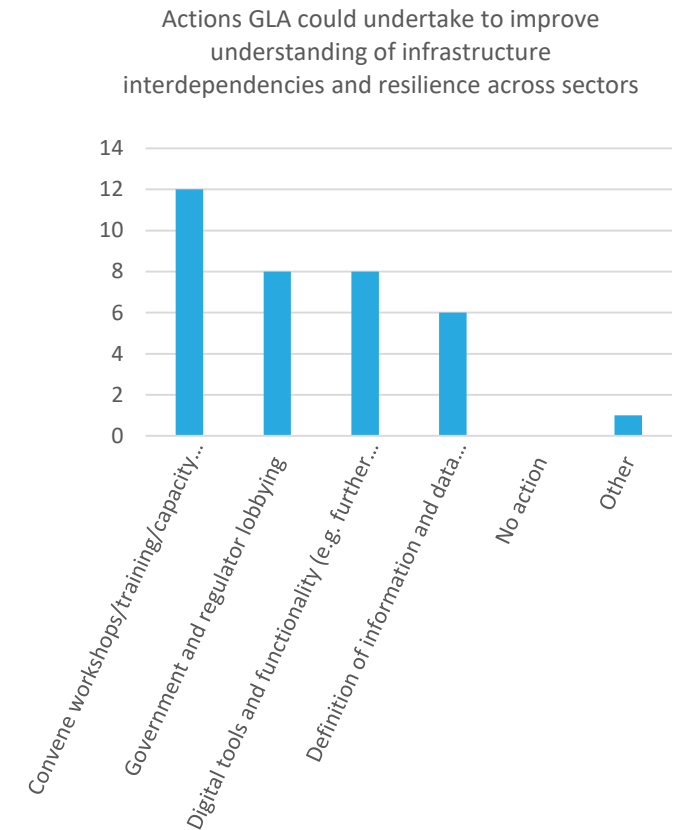


Figure 13: Extract from survey in response to question “What actions should the GLA undertake to facilitate information sharing to improve understanding of infrastructure interdependencies and resilience across sectors?”



7. Recommended actions

R2. Implement new functions into the IMA

Several new digital solutions were proposed that could be implemented within the IMA, some of which may still be underway at the time of writing. The functions identified by this study, in order of most benefit to the stakeholders, are:

- Ability to view asset criticality data.
- Ability to view asset health and condition information (this is underway but this project underlines the importance of the work).
- Ability to view current and future electric vehicle charging points (to support electric vehicle fleet rollout).
- Assessment of the cumulative impact of smaller scale developments (including commercial and residential, alongside infrastructure).
- Ability to view deprivation and inequality data.

As R1 is being implemented, it will allow further exploration of data requirements for the IMA.

The assessment of how much benefit would be accrued was undertaken using analysis of the interviews and the survey, as well as the multicriteria analysis.

There are additional items, not as much of a priority, listed in the long list of user stories in Appendix D. The first action should be to examine the data architecture required for these new functions, and only when the implications to the existing IMA are understood should these ideas be implemented. The ultimate aim would be to provide an information model of infrastructure

interdependencies that enables identification and prioritisation of interventions that build and support the resilience of London's infrastructure.

R3. Raise stakeholder awareness of the IMA

This study provides a clear indication of the appetite for and potential value of deploying digital tools to aid resilience planning. The IMA is already going to some length towards this by providing access to useful data and information in a secure and neutral environment.

However, about half of the survey responses indicated that stakeholders were not aware of the IMA application or were not using it. This may be due to the existing users of the IMA having a different focus (e.g. street works coordination) than the stakeholders engaged as part of this study (i.e. resilience decision making).

The GLA should take action to raise stakeholder awareness of the IMA e.g. through showcase events, webinars, increased engagement. As a first step, these materials should be disseminated to stakeholders of this project. This recommendation follows from R1 and R2, and will result in a greater uptake of the IMA.

R4. Seek to influence regulation

A number of individuals expressed the importance of the regulator in facilitating cross-sector interactions, particularly when it comes to understanding interdependencies and cross-sector investment opportunities.

Ofwat, Ofgem, ORR and Ofcom require the infrastructure operators they regulate to submit price reviews every 5 years. They are required to take on board stakeholders' viewpoints as part of this process.

We recommend that a timeline is created to identify where opportunities exist for the GLA to input to and influence regulated price reviews, in addition to where they may do so already. This should also highlight the requirements of each regulator around resilience (e.g. Ofwat's requirements for financial, corporate and operational resilience).

The National Infrastructure Commission's resilience study recommendations [6] included a requirement for regulators to provide guidance on cross-sector interdependencies and for operators to develop resilience strategies. It is recommended that the GLA Infrastructure team lobby for the implementation of these recommendations. If agreed by government, the team are in an excellent position to support organisations to develop their resilience strategies e.g. by facilitating ongoing interdependency working group. This is a good opportunity for the GLA to influence the next planning period.



7. Recommended actions (cont.)

R5. Promote consideration of cross-sector benefits

As outlined in the conclusions, stakeholders highlighted that funding for cross-sector activities is difficult, and that traditional cost-benefit analysis is not adequate for assessing benefits delivered by resilience-led schemes, particularly those that have a cross-sector impact.

To promote the implementation of cross-sector benefits, the GLA infrastructure team should:

- Incorporate shared resilience benefits into Framework Alliance Contracts workstream.
- Engage with the UK Regulators Network on cross-sector resilience.
- Share emerging best practice on assessment of resilience benefits.

In the medium term this would allow the team to lobby regulators to include measurement of cross-sector benefits in 5-yearly price reviews. Other useful actions under this umbrella include facilitation of a workshop to share how different infrastructure providers carry out assessment of resilience benefits, and facilitation of knowledge sharing on criticality methodologies they use.

R6. Widen the scope of stakeholder engagement

The stakeholders interviewed and consulted with held roles primarily in the strategic and tactical planning areas. There is merit with engaging with individuals that have roles across all planning levels as they will have different requirements and levers. It is important that a resilience ‘line of sight’ is maintained across all levels of decision-making to ensure that lessons from operational planning as well as emergency and business continuity planning are fed back to those concerned to planning for the medium and long term.

The GLA should also consider widening out to end-users of critical infrastructure systems that provide critical services such as healthcare, emergency services (both first response and councils), financial institutions and large businesses who are critical users of infrastructure service. This will help not only to better understand the disruption caused by cascading failures, but also to capture additional requirements and information sources.

This is particularly relevant for recommendation R3, raising awareness of the IMA to beyond the existing users, but also to R1 on convening interdependency workshops.



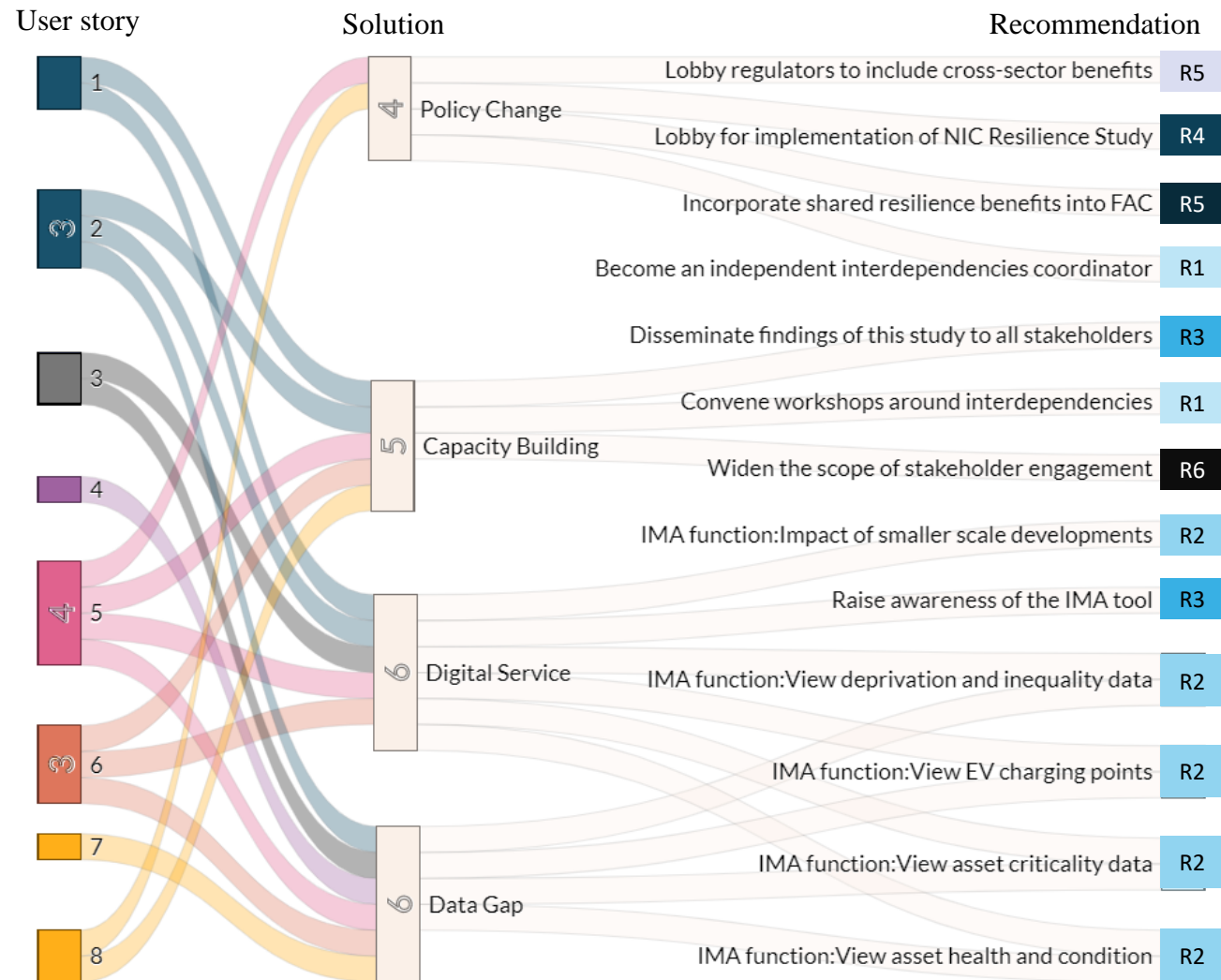
Figure 14: Infrastructure Regulatory Agencies



7. Recommended actions (cont.)

This page shows the prioritised user stories that were previously linked to solutions. This now shows the links between the solutions and the recommendations. The recommendations, outlined in full in the previous two pages, are based on workshop feedback and interpretation by Arup/UCL.

1. As a flood defence asset manager, I want to be able to understand asset criticality methodologies and data from other infrastructure providers, to develop an improved criticality approach for my flood defence assets.
2. As a flood defence asset manager, I want to be able to view asset health and condition information from other infrastructure providers, to understand if there are shared maintenance opportunities.
3. As an infrastructure operator/developer/asset manager I want to assess the cumulative impact of smaller scale developments that are not systematically logged so that I can flag potential risks to infrastructure capacity & resilience before they occur
4. As an infrastructure owner/developer/manager I want to improve the reliability and speed of access to information to streamline the way in which information is shared and used.
5. As an operations manager, I will be able to understand where I have dependencies with other infrastructure providers to facilitate conversations around ensuring their resilience.
6. As a power network planner, I want to know or estimate the locations of current or future electric vehicle charging points so that I can ensure capacity can meet the additional demand.
7. As an infrastructure planner, I want to view deprivation and inequality data so that I can assess the impact of investment planning on socio-economics.
8. As a gas distribution network manager, I want to consider the cost and demonstrate the benefits of resilience schemes so that the best value for customers can be sought.



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