Testing Innovation in the Real World

Real-world testbeds

Siri Arntzen, Zach Wilcox, Neil Lee,
Catherine Hadfield, Jen Rae

October 2019

nesta

Acknowledgements

This report has come about from the insight and guidance of a variety of professionals in a range of institutions. We would like to express our gratitude to the following for their participation, advice, insights and time through interviews, workshops, feedback and other similar activities.

With thanks to **Kirsten Bound** for original inspiration and thought leadership throughout the research, and **Tom Bridges** for his expert advice and project leadership of the Arup team. **Harry Armstrong**, **Olivier Usher** and **Nancy Wilkinson** for their comments on drafts.

Workshop and interview participants

Will Cavendish, Former Senior Responsible Officer for NHS testbeds, **Tim Armitage**, Associate Director at Arup, specialising in testing new transport technologies, **Lynne Miles**, Associate Director, Arup's City Economics team, Evaluation expert, **Nicole Mather**, Previously Head of Strategy in the Offices for Life Sciences (OLS) and SRO of testbeds, **Michael MacDonnell**, Previous Head of the Testbeds Programme for NHS England, **Brian Matthews**, Head of Transport Innovation, Milton Keynes City Council, **Luis Manoz**, Project Coordinator and Research Lead, Smart Santander, **Filip Kjeldgren**, Administrative Officer, Vinnova, **Thomas Sunden**, Project Lead, Energy Efficiency, Sustainable Innovation, **Professor Carlo Ratti**, MIT, Roboat , **Maria Strömberg**, Chair of Testbed Gothenburg, **Lars Bern**, Area manager for innovation for Testbed Gothenburg programme, Augustin Boey.

Project team

Tom Bridges, Arup, **Zach Wilcox**, Arup, **Siri Arntzen**, Arup, **Professor Neil Lee**, LSE, Catherine Hadfield, Arup.

About Nesta

Nesta is an innovation foundation. For us, innovation means turning bold ideas into reality and changing lives for the better.

We use our expertise, skills and funding in areas where there are big challenges facing society.

Nesta is based in the UK and supported by a financial endowment. We work with partners around the globe to bring bold ideas to life to change the world for good.

www.nesta.org.uk

If you'd like this publication in an alternative format such as Braille or large print please contact us at: **information@nesta.org.uk**

nesta

Design: **Green Doe Graphic Design Ltd**

Testing Innovation in the Real World

Real-world testbeds

Foreword

Testbeds are common in business. Companies try out new products and services in real-world conditions to see if they work, if consumers like them or if they throw up unexpected problems. What works on a screen or on paper often doesn't work in reality. Insights come in rapidly once an idea is being tried out in the messy and demanding conditions of everyday life.

But what about testing bold ideas and solutions that have the potential to solve some of the biggest challenges we face as a society? This report provides a survey of how testbeds are being used in areas that involve a public benefit or value – and also where there are gaps. It shows how many are being run to explore the technologies of the fourth industrial revolution: the Internet of Things, new forms of mobility, energy and housing. But it also shows that they are not being used much for mainstream public services, from schools and public health to police forces and welfare offices.

We think that testbeds could and should be used more widely, and that much more of society could be a living laboratory for new ideas and technology. This can help avoid unnecessary mistakes and wasted spending, as these ideas are tried out before they are implemented more widely. It can also ensure that innovations not only serve the public but are seen to serve them too.

Testbeds have become an important area of practical work for Nesta. We are involved in testbeds for drones (through our Flying High programme), for educational technology (through our EdTech Innovation Testbed) and for uses of Artificial Intelligence (AI) in the labour market and other fields, alongside many other experiments and sandboxes through programmes like the Innovation Growth Lab, which runs dozens of RCTs linked to industrial policy.

We commissioned this research to get a sense of the landscape of testbeds around the world. How are they designed? What works for different purposes? How could they be used more actively? And what can we learn from these examples to spread good practice? The answers to these questions will help both public and private sector to design more effective testbeds.

In some fields, such as transport technology, they are becoming mainstream. But testbeds should be more integral to major streams of public research and development aimed at solving some of the world's global challenges. Action to mitigate climate change is an obvious one: we need much more active experimentation around promising applications, from zero carbon buildings to new ways of motivating the public to change their behaviour.

AI is another one. So far too much research is being done in the lab, and with too little understanding of how AI can support human decision-makers in real-world conditions. There are increasing numbers of testbeds in healthcare, such as the UK's NHS innovation testbeds (a case study in this research) and in technologies to support healthy ageing. But it's still remarkable that whereas there are very expensive systems for testing out new drugs, there is still little comparable machinery to test out public health innovation such as digital apps that might help with mental health conditions, or new models of peer-to-peer support.

More active experimentation in all of these fields should pay big dividends. But the biggest value will come when the knowledge that is gained from testbeds is synthesised and made useful for everyone else. One of the key findings from this research is how little emphasis has been placed on evaluation as part of setting up testbeds. This orchestration of 'what works' is still too often an afterthought, or no one's job. We need more testing; but we also need much more intentional learning too, to truly harness the power of experimentation.

Geoff Muglan
Chief Executive,
Nesta

Executive summary

Testing out how new ideas and technologies work in practice is a critical part of ensuring that they are both fit for purpose and safe before they reach a wide audience. Scientists, businesses and – increasingly – governments, look to test innovative products and services before they enter our homes and cities, or are applied to our public services.

This experimental approach to testing innovation is an opportunity to make innovation safer whilst also maximising real-world positive impact. It offers a way of finding out how new ideas and technologies can be applied to solve society's biggest challenges, such as climate change, healthy ageing and inequality. It should also provide a setting for establishing how governments, businesses and citizens can all benefit from innovation.

In this report we focus on testing environments which are both bounded and real-world settings, or close to real-world settings, and explore examples of experimentation which have taken place in this environment. We term these real-world testbeds, and we set out to learn more about how they are being used across the world.

Based on a review of 95 real-world testbeds, this report investigates how they are being used to stimulate innovation and draws out lessons for policymakers who are considering setting one up.

The report will help improve understanding of how real-world testbeds work and how they fit within the innovation process and landscape. We hope it will be used by public sector stakeholders, regulators and private sector firms to design effective real-world testbeds.

Real-world testbeds: What are they and why do they matter?

In the report, we begin by explaining different categories of testbeds, but our focus is on the specific category of 'real-world testbeds', which we define as:

> "Controlled or bounded environments for testing innovation in real-world, or close to real-world, conditions in the manner (or close to the manner) in which they will be used or operated."

Our research shows that developing real-world testbeds can help people and places to:

- **Strengthen collaboration** within a clear and structured framework between the public sector, business, universities and other research-intensive organisations.
- Focus and **attract investment and resources** in innovation in specific technologies, sectors and research areas where the local area is seeking to develop and strengthen a competitive advantage.
- **Reduce risk** in the process of developing new products and processes for firms, providing a safe space for them to iterate, fail, influence regulatory and policy change and support them to develop to an investment-ready stage.
- **Promote the local area** as a good place to invest and develop knowledge-intensive functions, giving potential investors and existing firms in the area confidence that there is a supportive and enlightened local innovation ecosystem.
- **Improve the delivery of (or reduce the demand for) public services** by creating the right policy, governance and regulatory systems.
- **Maximise the economic potential and value of research** done locally, and of other assets such as public-sector data.
- Make better use of publicly-available **infrastructure**.
- Provide a framework for innovation policy that enables **effective evaluation**.

To take advantage of the opportunity that real-world testbeds can bring, our recommendations from this research are:

1. **Real-world testbeds are an important policy tool that can increase innovation and achieve the aims of national and local industrial strategies**. Our research shows that they can play multiple roles for national and local government, set out in the use-cases in this report.
2. **Governments should experiment with applying real-world testbeds as a tool for solving grand societal challenges**. Real-world testbeds offer an opportunity to incentivise and co-ordinate across public, private and third sectors to work together in directing their efforts at solving challenges. This use of real-world testbeds is currently under-represented in our research.
3. **Public engagement should be central to the design of testbeds and considered from the start**. A framework for how the public will be engaged and involved should be set out from the start of the design phase of a real-world testbed. Real-world testbeds can raise significant ethical questions, including those around the type of technologies which are tested and the consent of those who are in the testing environment.
4. **Governments should compile a national overview of the infrastructure available to test and demonstrate innovation**. As demonstrated in our example from Sweden, this would allow these tools to be marketed and help coordinate resources and learning from them.
5. **Relevant governmental and/or innovation agencies should agree on a shared terminology for testing and demonstration tools as confused terminology prevents learning**. Our research aims to provide a basis for a shared terminology.
6. **Real-world testbeds should not be stand-alone policies, but part of a strategic approach**. The best examples from our research embed the testbed in a wider strategy based on research strengths.
7. **Evaluation and learning should be considered from the start of real-world testbed design**, to understand the impact of the innovation being tested, but also the process of testing. Evaluation is too often an afterthought rather than a core aspect of the testbed design, leading to the loss of important learning and evidence. Our report highlights several examples of approaches that could be taken.

1 Introduction

1.1 Real-world testbeds as innovation policy

Testbeds are an increasingly used innovation policy tool. As a common term they refer to testing and demonstrating infrastructure within environments such as laboratories, simulated or constructed environments, and real-world environments. The Swedish innovation agency Vinnova refers to these three environments as Level 1 (laboratories), Level 2 (simulated or constructed environments) and Level 3 (real-world environments used for testing innovation). This report mainly focusses on Level 3: real-world testbeds.

One of the core challenges in bringing innovation to market, and securing economic and societal benefits from it, is enabling innovators to test new technologies and their use cases in the real world. Innovation may work well in laboratory conditions, but they could fail or behave differently when introduced into the environments they are intended for – often complex, adaptive, real-world systems. For example, autonomous vehicle technology may work seemingly well in laboratories or test tracks but may be unable to cope when confronted with the unpredictable human traffic environment.

To address this challenge, policymakers and institutions are increasingly enabling the testing of new technologies in bounded, real-world environments. New financial technologies have been tested with flexible regulation on small groups of users, for example, and sensors have been deployed in a city district to test various smart city solutions. There is no consistent definition for this sort of policy instrument, and they are known by different names including 'demonstrators', 'sandboxes' or 'testbeds'. This report focusses mainly on testbeds operating in real-world environments, and we term these 'real-world testbeds'.

Real-world testbeds share two common features. First, they are environments designed to contain risk. Their bounded nature has several advantages: it allows the management of risk, reduces the challenges associated with the regulation, provides access to specialist infrastructure, and secures access to specific user groups or associated data. Second, they enable the testing of new technologies in real-world conditions, providing a framework for learning, evaluation and adaptation in a controlled process. Their real-world nature distinguishes them from laboratories or simulations, which tend to reduce the complexity of real life. Real-world testbeds are designed to test technologies in the complex systems in which they will ultimately be used.

Facilities for testing are an increasingly important part of the innovation infrastructure, required to keep up with the pace of technological development. With part of the real world available to innovators – be it a road, an airfield, a neighbourhood or an elderly care centre – technologies can be introduced relatively safely and tested in various use cases when they are close to commercialisation. Understanding how to facilitate real-world testbeds can also help public, private, and other stakeholders collaborate, and ultimately be better positioned to solve critical, societal challenges together through the innovative process.

The public and private sectors can use real-world testbeds for a variety of purposes – each of which shapes the requirements and design of the bounded environment. This report discusses these purposes and their impact on the use of testbeds.

1.2 Purpose of the report

This report is for those developing and implementing testbeds, including policymakers in national and local governments, private and third-sector developers of technology, researchers, and agencies tasked with promoting and facilitating innovation. The report provides insights to help them understand, design and implement successful testbeds in the real world and learn from previous examples.

Based on a review of academic and other literature, a review of global examples of testbeds, and in-depth case studies, we investigate and clarify what testbeds are, distinguish them from other similar innovation tools, and illustrate different ways of using testbeds for various purposes and actors.

Based on the research findings, this report sets out points to consider when designing a testbed, to ensure the safe and effective introduction of new technologies in ways that maximise potential economic and social benefits.

The report should be read and used by:

- Anyone interested in understanding real-world testbeds and how they fit within the innovation process and landscape.
- Public sector stakeholders or others with access to real-world environments wanting to explore opportunities to develop real-world testbeds.
- Regulators seeking to explore opportunities of getting involved in real-world testbeds.
- Private sector firms seeking to use real-world testbeds.

2 Methodology

2.1 Literature review and bank of examples

A review of academic and other literature was undertaken. This facilitated a greater understanding of the terminology and the type of tools used for testing innovation and identified main principles and lessons valid for real-world environments.

Comprehensive desk-based research was undertaken of relevant examples of testbeds from across the world, developing and using a set of criteria to classify these examples. These have been brought together in a 'bank of examples' for this study. Because there is already literature on laboratories (which test new technologies in closed conditions), the focus of this research was on testing facilities which tested innovation in the real world. Box 1 sets out the criteria for inclusion of case studies in the bank of exampless for this report.

Box 1. Criteria for inclusion of testbeds in the bank of examples for this study

- Does it test a new technology or an existing technology in a new or innovative context?
- Does it lower barriers to testing through one or more of the following:
  - Risk management.
  - Regulation.
  - Access to user-groups.
  - Access to physical/technical infrastructure?
- Is it in a real-world (or close to real-world) environment?
- Does it allow failure, learning and evaluation in a testing phase?
- Has it got some form of public sector involvement?

Over two hundred testing and demonstration facilities were reviewed, informed by our literature review and various terminologies in different languages. This resulted in a sample of eighty examples of real-world testbeds (available in Appendix 1).

These examples exclude closed facilities for testing Connected Autonomous Vehicles (CAVs) or laboratories testing various technologies. The sample was by no means exhaustive. Thousands of testbeds exist across the world, under different terminologies and across sectors. The full list of real-world testbeds included in the Bank of Examples can be found in Appendix 1.

The geographic spread of the sample of examples can be seen in Figure 1.[1]

Figure 1: Geographic distribution of real-world testbed examples considered for this study

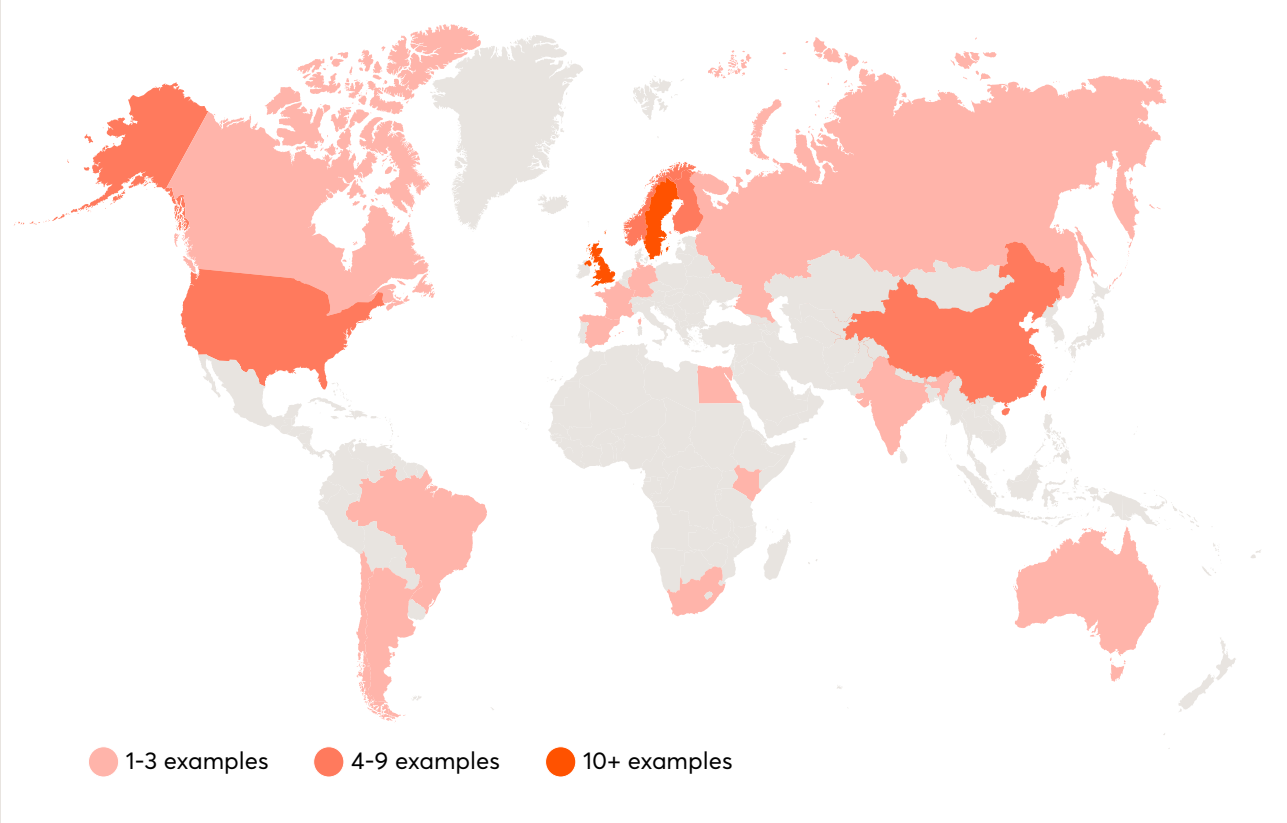
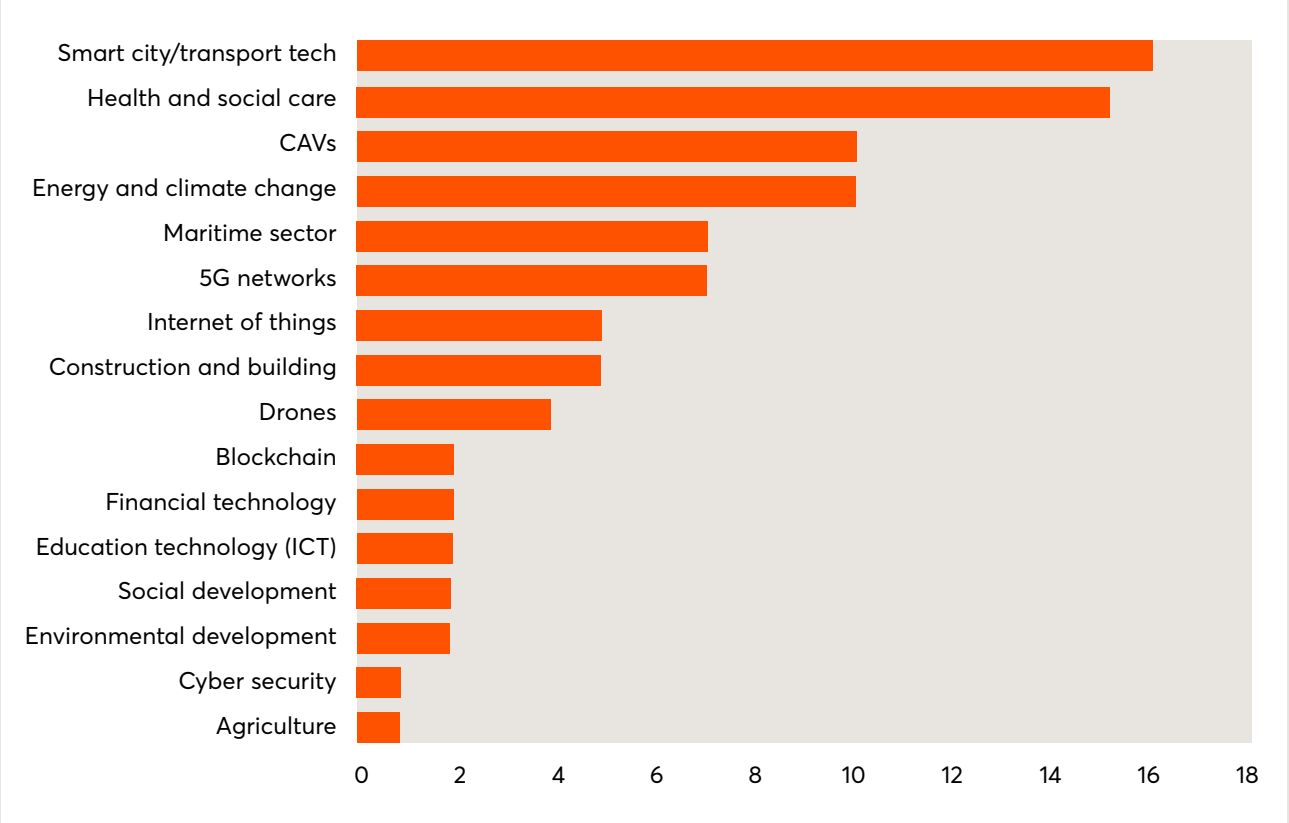


Figure 1 illustrates the spread across sectors and technologies identified in the examples for this research.

Figure 2: Testbed examples considered for this project by sector and technologies



The majority of the identified testbeds operate within smart city and transport technology, health and social care, CAVs, Energy, 5G technology and Internet of Things (IoTs). This is not necessarily reflective of the full global spread, it represents the sample of 95 real-world testbeds identified through this research.

Some transport and smart city real-world testbeds are very specific, such as ElectriCITY in Gothenburg, focusing solely on testing public transport solutions. Others, such as Smart Kalasatama in Helsinki (Finland), take a more open approach, making a new neighbourhood available for testing various technologies that contribute to the overarching objective of "saving the inhabitants one hour per day in efficiency solutions."[2]

Some of the examples are projects with a set of pre-identified partners from across sectors, while others are open to continuous enrolment to provide innovators with access to the testbed.

2.2 Case studies

Based on an in-depth review of the bank of examples and discussions with a network of experts listed at the start of the report, six case-studies were chosen for detailed review. Table 1 provides an overview of the case studies.

The case studies are in Appendix 2 with full descriptions and an overview of the main findings. These findings are used, along with insights from the broader bank of examples, to inform the framework, arguments, and recommendations in this report. External and internal experts with various experience have contributed to the report in several workshops and feedback sessions.

Table 1: Case study overview of detailed case studies (see Appendix 2 for the case studies)

Testbed (geography)	Description	Method
NHS testbeds (England)	A national testbed programme for health technology deployed with a range of different patient groups in hospitals and local NHS bodies.	Desk-based research and three interviews
Roboat (Netherlands)	An autonomous vessel testbed in the canals of Amsterdam, testing various use cases such as freight and passenger transport, environmental monitoring and temporary infrastructure.	Desk-based research and e-mail interviews
National Testbed Strategy (Sweden)	A national strategy set to coordinate existing test and demonstration facilities across Sweden, aiming to ensure collaboration and shared learning between them, a holistic approach to innovation testing policy and mitigating for lack of investment in less mature technologies.	Desk-based research and three interviews
Testbed Gothenburg (Sweden)	The city of Gothenburg's local initiative to coordinate testbeds and market the city based on their existence.	Desk-based research and two interviews
Milton Keynes	A testbed facilitated by Milton Keynes City Council, being open to testing transport technologies in the urban environment, including autonomous vehicles and delivery robots.	Desk-based research and two interviews
Smart Santander (EU: focus on Spain)	An IoT testbed facilitated by the EU and the city of Santander, deploying sensors in the urban environment for smart city purposes.	Desk-based research and two interviews
Digital AV testbed	A concept for the 'Cross-Border Digital Test Bed': A real-world testbed aiming to test AV technology and adapt the regulatory environment of autonomous vehicles on various types of roads between France, Luxembourg and Germany.	Desk-based research and one interview

3 What are real-world testbeds?

3.1 Overview

The terminology around testbeds is fuzzy and unclear. Tools enabling experimentation, testing, and the managed introduction of new technologies are sometimes called 'demonstrators', 'sandboxes', 'testbeds', and 'living labs'. While there is increasing use of these terms, there is little consensus about their precise definition. This report uses the term 'real-world testbed' because of the focus on the real-world element. This section of our report defines real-world testbeds, explaining how they are distinct from other similar policy tools, and argues why they are important to various stakeholders.

3.2 The literature on testing and experimentation tools

Providing virtual or real-life spaces for experimentation and testing is an increasingly important part of innovation policy. Trial and error learning has always been essential for innovation, but this has generally been in environments which simplify real life, reducing the number of parameters, rather than being a real-world situation.[3]

The increased importance of real-life testing has been driven by two changes. The first is the growing importance of smart city type technology. This has made it easier to evaluate the performance of new technologies, as the increasing use of real-time monitoring and sensors allows authorities to monitor what is happening – a phenomenon sometimes called 'test-bed urbanism'.[4]

At the same time, regulators have been looking for new strategies to manage the pace of technological change.[5] While many interventions can be tested immediately in real-world situations, this is more challenging when testing in a complex system where the "challenges of complexity that arise in any interactions among institutional, technological, and human systems" are obvious.[6]

The Organisation for Economic Co-operation and Development (OECD)[7] classifies testbeds as "testing environments (or test beds), where new technology developments can be tested in controlled but near to real-world conditions." They distinguish these from regulatory sandboxes, which provide waivers from regulation, allow companies to trial new products and allow regulators to learn as well.

The use of real-world testbeds is also on the rise, specifically in the Nordics and the UK. In Sweden, a country with highly developed testing and demonstration infrastructure, the number of real-world testbeds now represents 40 per cent of all the available tools for enabling testing of innovation, in addition to being at the top of the Swedish government's list of innovation priorities. Real-world testbeds have received growing interest across the UK through projects such as UK Auto drive, NHS testbeds and numerous 5G testbeds. Nesta has also published research on how EdTech testbeds are being used around the world, suggesting four models for how these could be used in the UK.[8]

3.3 Defining and positioning real-world testbeds

Based on an in-depth review of the Bank of Examples and discussions with a network of experts listed at the start of the report, six case studies were chosen for detailed review. Table 1 provides an overview of the case studies.

The case studies are in Appendix 2 with full descriptions and an overview of the main findings. These findings are used, along with insights from the broader bank of examples, to inform the framework, arguments, and recommendations in this report. External and internal experts with various experience have contributed to the report in several workshops and feedback sessions.

The definition for this research

'Testbeds', or 'test and demonstration infrastructure' in their broadest form include all different types of environments. The Swedish Innovation Agency, Vinnova, categorises them as Level 1 (laboratories), Level 2 (constructed/simulated environments), and Level 3 (real-world environments). Real-world testbeds, the focus of this report, provide environments where innovation is tested in collaboration between users, innovators and, often, regulators and other institutions in the environment where the technology will be implemented. From the public sector perspective this can, for example, be opening up bounded environments for testing specific infrastructure, public systems such as health care, or real districts of a city.

Real-world testbeds are defined as follows in this report:

Box 2: Definition of real-world testbeds

"Controlled or bounded environments for testing innovation in real-world or close to real-world conditions in the manner (or close to the manner) in which they will be used or operated."

- They reduce the barriers to testing by helping manage risk, changing regulation, allowing access to user groups, or providing a specific physical environment.
- They are particularly suited for technologies which operate in complex systems or in challenging ethical contexts. The use of a testbed allows the management of risk, experimentation, evaluation, and failure.
- Because the focus is on testing in real-world environments, they are suitable for higher technological readiness levels, where technologies have already been tested in simulated environments.
- Because they allow technologies to be tested in a manner in which they would not otherwise be tested, they encourage investment in innovation.

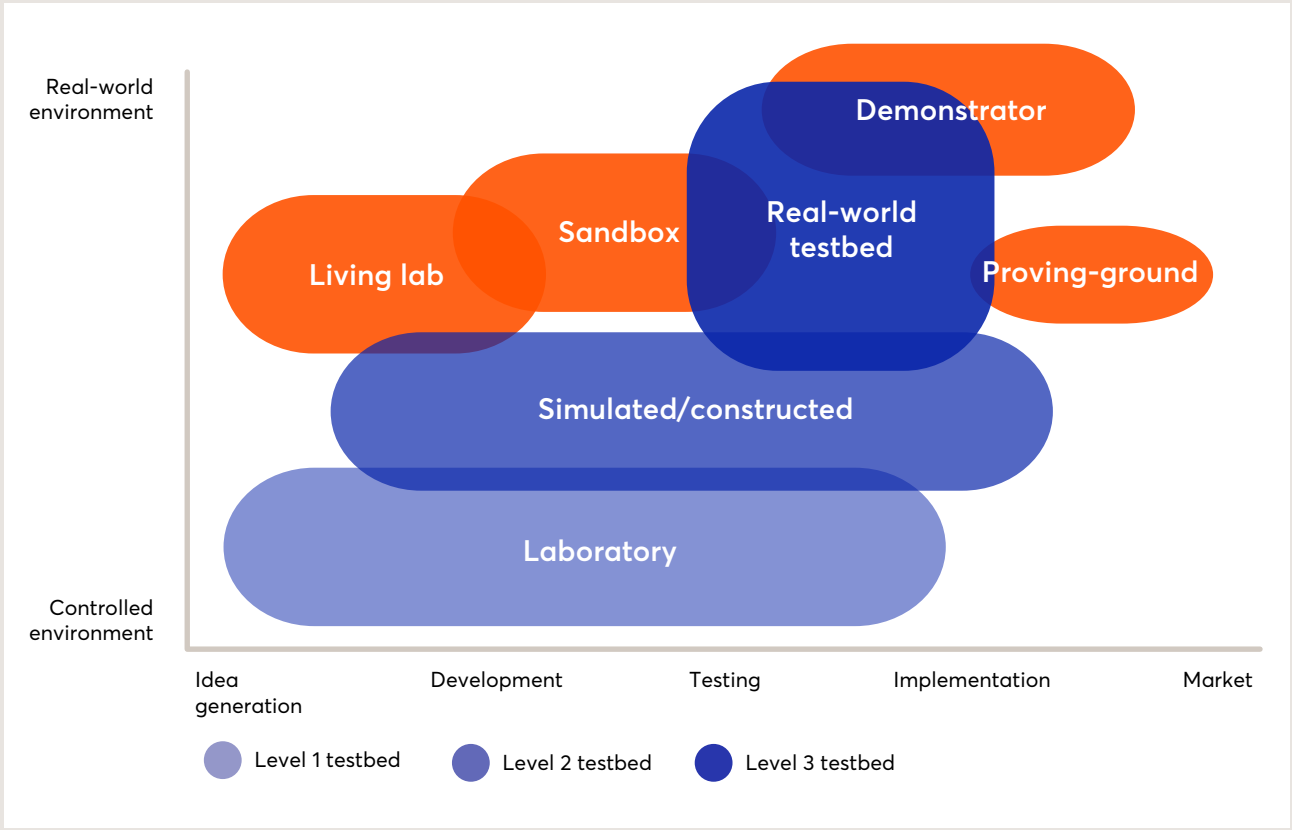
How real-world testbeds overlap with innovation testing tools

A categorisation of innovation testing tools was developed, informed by the literature review, expert interviews and case studies. Testing and experimentation tools vary in two main ways. First, they vary according to the degree of control in the environment in which they operate. Laboratories are attempts to control the environment in which testing and experimentation occurs, reducing the number of variables which might interfere with outcomes. Other technologies can only be tested in real-world environments, in which cases real-world testbeds might be more suitable.

Second, these tools differ according to the relevant stage of the innovation process. Some of these tools, such as living labs, tend to be designed to create new ideas.[9] Others are used for technologies which are near to market, with proven or near-proven technology such as demonstrators or use cases.

We use this division to map out the different type of innovation and testing tools. Figure 3 plots the innovation stage on the horizontal axis, from idea generation through to development, testing, implementation and market. The vertical axis represents the amount of control in the testing environment, spanning from completely 'controlled' (a laboratory) to real-world environments.

Figure 3: Real-world testbeds placed among other test and demonstration terminologies



While there is no settled definition in the literature and terminology is often fuzzy, our research situates real-world testbeds as being those which are at the testing or implementation phase, but which involves them being in a real-world environment. The concept of real-world testbeds overlaps with the concepts of demonstrators, sandboxes and proving grounds, but are relatively analytically distinct from living labs and laboratories. In particular, there is considerable overlap with the term demonstrators, a term which was originally used to refer to products which were very close to market (therefore needing 'demonstration' rather than 'testing').

The following section provides explanations for each of the terms, underpinning their placement in Figure 3. In future, it is important to distinguish these as different tools to avoid confusion and improve the understanding of when they should be applied. Although they will continue to overlap to a certain extent, as they all operate in similar areas of the innovation process, in future it is important to improve our understanding of what makes them different.

- **Laboratories (Level 1 testbed[10])** are strictly controlled test sites where innovators can test specific technical properties in isolated, artificial and heavily controlled circumstances. They are often limited to part-functions and components rather than systems or production methods. They tend to be clearly distinguished from our definition of real-world testbeds, but they are commonly referred to under an umbrella 'Testbed' term which encompasses all environments that allow testing of innovation.

- **Simulated/constructed testbeds (Level 2 testbed[11])** are areas for testing and verifying systems, process and product levels. The environments are closed-off areas and test facilities (e.g. closed-off tracks for testing autonomous vehicles). They often offer a simulated or constructed version of reality, still closed off and able to control by the testers. Figure 3 places these testbeds in spanning from development to implementation in the innovation process, between fully controlled and real-world environments. Simulated testbeds often overlap with real-world testbeds as they sometimes occur in combination (a testbed offering both simulated and real-world environments).

- **Real-world testbeds (Level 3 testbed[12])** are controlled or bounded environments for testing innovation in real-world conditions in the manner (or close to the manner) in which they will be used or operated. This report's definition is based on Vinnova's Level 3 definition.

- **Sandboxes** are described as follows by Ribiere and Tuggle:[13]

> "The idea behind the innovation sandbox is to create a 'space' (often virtual) in which developers can play around with an innovation to get a feel for how it might be used, add/delete features to it, comment to one another about it, ask a variety of 'what-if' questions of others playing in the sandbox about the innovation and related innovations… (and)…show it virtually to prospective purchasers/users of the innovation to get their reactions, ideas, and suggestions."

Some sandboxes operate in close to real-world environments, for example through testing regulation in closed-off elements of financial systems, while others such as the CAA sandbox operate as an advisory service for innovators wanting to operate in the commercial drone landscape. As illustrated in the figure, they stretch across controlled and real-world environments, available in the development phase and the testing phase of various innovations.

- **Living lab** is the term that is most fuzzy and difficult to pin down into one, agreed definition. The European Network of Living Labs defines them as "user-centred open innovation ecosystems based on a systematic co-creation approach, integrating research and innovation process in real-life communities and settings."[14] Based on this and other definitions,[15] Living labs operate in simulated or real-world environments focussing on the co-production of products. This is in an earlier stage of the innovation process than real-world testbeds.
- **Proving ground** is the tool often used to test products within transport, to ensure they fulfil industry requirements and standardisations. Definitions are often found within the specific industries, for example by General Motors:[16] "proving grounds exist to enable us to establish indisputable facts about automobiles in general. In other words, it is necessary to provide facilities for the comparison of all cars; a place where we can evaluate GM cars against all other products." We have placed Proving Grounds in the 'implementation' stage of the innovation process, in simulated or real-world environments.
- **Demonstrator** is the term that most closely overlaps with real-world testbeds and is sometimes used interchangeably. The European Commission described the purpose of a Demonstrator *"to validate the technical and economic viability of new or improved technology, product, process, service or solution in an operational (or near to operational) environment, whether industrial or otherwise, involving where appropriate a larger scale prototype or demonstrator."* Examples of Demonstrators suggest that the most apparent distinction from real-world testbeds is that Demonstrators focus on more mature technologies and can thus operate in more real-world environments, demonstrating their market-readiness in the stage before market implementation.

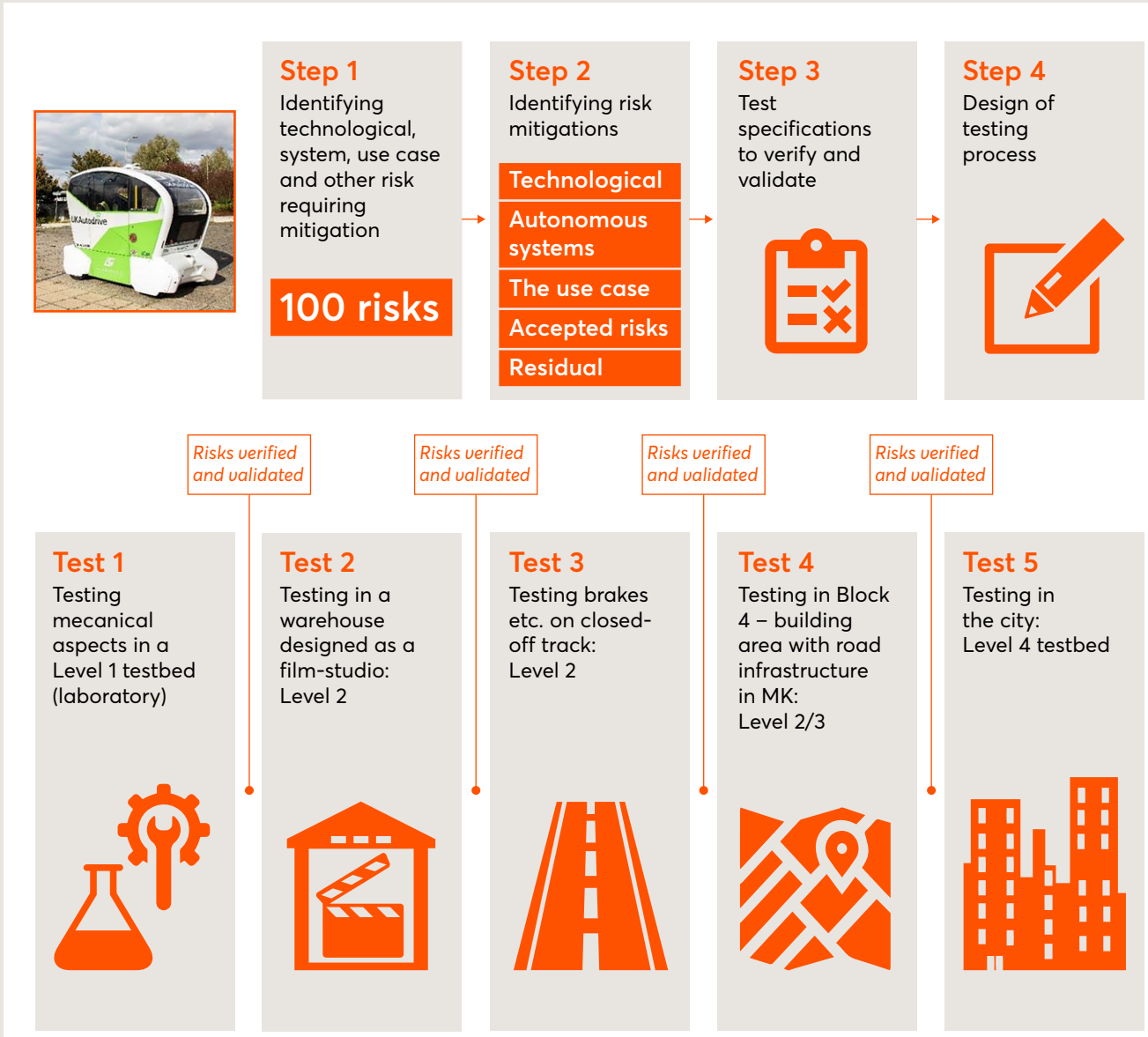
When might different tools be used?

As seen from the previous section, there are sometimes subtle differences between various tools used throughout the innovation process. Despite these differences, the various tools are required at different times in the innovation process for specific reasons.

Which environment is used and the level of control of the circumstances is directly associated with how safe and mature the innovation is. Taking autonomous vehicles as an example, the technology needs to be highly mature and proven to be safe before they are tested alongside the many unpredictable elements of real traffic. If there are risk mitigations that cannot be properly evidenced, a more controlled environment should be selected before allowing testing in the real world. If enough evidence has indeed been provided that the technology is safe (evidence that recognised risks have been tested and mitigated in labs and closed environments previously with successful and robust results), real-world environments can be considered.

To illustrate this, Figure 4 illustrates how and when various environments were used during the project UK Autodrive, deployed in Milton Keynes. UK Autodrive was one of the transport innovations tested in and around the city of Milton Keynes. The testing was designed based on a risk register listing all the potential aspects that could go wrong on various levels. The majority of these risks (except a residual that was accepted in collaboration with insurance companies), required evidence of mitigation that needed to be proven in different testing environments. Some risks could be mitigated through modifying the technology or the autonomous systems, others through limiting what the pods could be used for.

Figure 4: Example of an innovation process using different tools



The mitigations guided the design of the multiple tests required to prove the safety of the pods. Those relating to the technology needed to be tested in completely controlled laboratories (described as a 'treadmill for cars'). Once mitigations had been sufficiently proven, the next step was testing the pods in various weather conditions and controlled obstacles in a simulated testbed (similar to a film set). The third step was to test the vehicles on closed-off testing tracks before moving on to real-life conditions without users (close to real-world conditions). Finally, the pods were tested in the city of Milton Keynes. Before reaching this point, the testing would move back and forth between the previous testing environments if it was deemed necessary to retest or reassess adjustments to the technology before testing in a more real-world environment.

Should a demonstrator be used in this case, it would, according to our definition, come after Test 5 when the pods had been proven safe enough to 'demonstrate' their ability to operate in real-world traffic. A living lab would not be compatible with testing such a risky technology, as it deals with co-development of technology with users. A living lab could be useful to test how the AVs were to be used, for example either through a shared model or privately-owned cars. A sandbox would be suitable throughout the process if the main purpose was to develop AV regulation, and it could be represented through, for example, the Department for Transport facilitating sessions with AV innovators to help them understand how to safely operate the rules.

3.4 Why, and for whom, are innovation testbeds important?

There are a series of actors leading, participating in, funding, or facilitating real-world testbeds. This report focuses particularly on why real-world testbeds are key for public and private sectors. They can be especially important as the rapid development of increasingly complex goods and services continues.

Actors typically involved in real-world testbeds

A range of actors are often seen to be involved in real-world testbeds.

- **Innovators**, either from the private sector or research institutions, are naturally always involved. However, anecdotal evidence points to large, resourceful companies or departments being involved more often. Small and medium enterprises (SMEs) are often harder to engage, although their needs may be as high.
- **The public sector** is often involved in testbeds, especially on the funding side. There is a strong case for the public sector to take greater ownership in real-world testbeds as this could influence the outcomes and objectives to become more socially beneficial.
- **Local and regional authorities** increasingly use testbeds for economic development purposes, as a piece of the innovation ecosystem.
- **Regulators** are involved in some testbeds, however, often in the least 'invasive' manner. They could be increasingly involved to allow a more experimental and anticipatory approach to regulation.
- **Universities** and other research institutions are somehow involved in the majority of real-world testbeds we have identified. It represents a great way of spreading the value of the researcher's expertise and promoting linkages with private innovators and the wider public sector.

Why real-world testbeds are useful for the public sector

It is increasingly important for public sector actors to develop new ways of delivering, or reducing demand for, public services to improve outcomes and reduce costs. They have access to various environments that innovators are keen to test in. Real-world testbeds have a potentially valuable role to play to ensure safe and effective use of new technologies across health systems, schools, mobility services, cities and regions.

For nations, cities and regions, real-world testbeds can play a role in supporting more productive economic growth, including attracting and retaining investment from knowledge-intensive firms, increasing the rate of start-ups and scale-ups amongst innovation-driven enterprises, and securing greater investment in R&D from existing large firms.

National and local governments and their agencies are aiming to maximise the diffusion of innovation – and to increase the stickiness of this locally – from research-intensive anchor organisations such as universities and other research bodies, hospitals and some public sector functions. They are also working to build stronger and larger angel investment/ venture capital networks, particularly in areas with low levels of risk capital investment. The public sector is also seeking to promote innovation to develop new ways of delivering, or reducing demand for, public services to improve outcomes for people and to save money.

These cities and city regions are seeking to put in place the right conditions and build the ecosystems to support innovation-driven growth and/or to improve public services, bringing together universities and other research-intensive institutions, entrepreneurs, corporates, venture capital investors and the public sector. To do this, local policy makers and stakeholders need to consider the range of tools and interventions at their disposal. Innovation testbeds have an important role to play alongside other policy tools such as living labs, pilots, open data and so on.

In particular, developing real-world testbeds can help places with:

- **Strengthening collaboration between the public sector, business, universities and other research-intensive organisations** within a clear and structured framework, which is necessary for developing an innovation-driven growth ecosystem.
- **Focusing and attracting investment and resources in innovation in specific technologies, sectors, and research areas** where the local area is seeking to develop and strengthen competitive advantage.
- **De-risking the process of developing new products and processes** for firms, providing a safe space for them to iterate, fail, influence regulatory and policy change needed, and supporting them to develop to an investment-ready stage.
- **Promoting an area as a good place to invest** and develop knowledge-intensive functions, giving potential investors and existing firms in the area confidence there is a supportive and enlightened local innovation ecosystem.
- **Improving the delivery of (or reducing the demand for) public services** through creating the right policy, governance and regulatory systems.
- **Maximising the economic potential and value of research done locally**, and of other assets such as public sector data.
- **Providing a framework for innovation policy that enables a more systemic approach to evaluation of effectiveness**.
- **Making better use of publicly available infrastructure**.

Why testbeds are important for the private sector and other innovators

For innovators, testing and verifying technologies or other innovations is vital to ensure the innovation is ready for the market. Several private companies run singular tests or pilots of their products, however this can be an expensive and complicated process, especially if resources are scarce. Testbeds can help businesses in:

- **De-risking the process of developing new products and processes** for firms, providing a safe space for them to iterate, fail, influence regulatory and policy change needed, and supporting them to develop to an investment-ready stage.

- **Building relationships with regulators and public sector**, of which the latter could be either local policy enforcers or potential customers.
- **Attracting venture capital investment** by providing robust evidence that the innovation is safe and fit for purpose in the environment where it is intended to be used.
- **Providing access to infrastructure, users (or their data), regulators and other key institutions, and professionals** in the environment they seek to innovate in. This is particularly important if the sector is highly complex and challenging to access, such as the financial sector, rail, or health care.
- **Gathering robust evidence** that technologies are suitable for the real-world environment and are well-received by the target audience, easing the road to commercialisation. This is naturally dependent on allowing the opportunity to involve users and/or 'customers' of the technology in the testbed design.

3.5 Real-world testbeds to watch

Real-world testbeds can naturally be as startlingly different as the real world itself, as reflected in our sample of 95 real-world testbeds spread across sectors, environments and scale. This section highlights some recent examples from our research that illustrates real-world testbeds' diversity and their sometimes controversial and surprising uses.

Unmanned Warrior Testbed: In 2016, unmanned systems were tested in conjunction with a major multinational naval exercise in Scotland and Wales. Among the many military vessels tested was the MAST (Maritime Autonomy Surface Testbed) system, a vessel able to operate at a fully autonomous level, and unmanned aerial vehicles. The six-week long test in the real world integrated 40 vehicles from land and sea in numerous scenarios, to allow the Royal Navy to see how autonomous systems and sensors could be integrated into future operations. This example illustrates how existing traditional formats such as naval or military exercises, normally conducted for testing and practising operations, can be used to test technology.

Sidewalk Toronto: Sidewalk Toronto is a partnership between the City of Toronto and Sidewalk Labs, an Alphabet subsidiary, intending to develop the 12-acre Quayside area along the Toronto waterfront. Sidewalk Labs' vision is to 'develop a fully connected neighbourhood and a testbed for digital innovations'.[17] Although not active yet, concerns have already been raised by the public regarding privacy and data harvesting, with fears of Quayside developing into a surveillance city instead of a smart city. This real-world testbed illustrates the immense importance of transparency and citizen participation when new technologies are to be tested and deployed in the real world.

Growth Corridor Finland: Home to a third of Finland's residents and approximately half of its businesses, Growth Corridor Finland functions as a real-world testbed for smart accessibility provided by convenient transport links and digital infrastructure. As a network of over 20 cities and municipalities, three regional councils, four chambers of commerce and four ministries, the real-world testbed aims to promote experiments and introduce new series and mobility practices and become the leading testing platform for new, smart, sustainable mobility. This real-world testbed illustrates the potential scale of the real-world environment operating as a testbed, and the opportunities for collaboration between stakeholders this method entails.

EnergyBlock (EG): EG is a real-world testbed aiming to explore the potential of using renewable energy sources in an existing urban neighbourhood and connecting them to an open blockchain for energy. The ambition is to validate the technology and the proof of concept to investors, citizens and decision makers with an aim to further scale the technology. Developed from a sustainability perspective, the real-world testbed will test and analyse the benefits of the local energy production alongside local food production and a social agenda of local job creation. This illustrates the opportunity of using real-world testbeds to test technologies combined with social or environmentally friendly approaches to urban life.

3.6 Main findings

- Real-world testbeds are part of a set of policy tools associated with experimentation and testing innovation. They provide environments for testing with two key features – they are real world and they are bounded. The combination of these two features means they can be used to manage the risk of introducing new technologies.
- Real-world testbeds are often confused with other, similar tools in the innovation process. Real-world testbeds are used when the innovation is deemed safe and mature enough to be tested in the real world. This distinguishes them from living labs, which are more often associated with the development of new ideas, although many living labs are described similarly to real-world testbeds. Some of the real-world testbeds this report focuses on are termed demonstrators.
- There are few limits to the extent stakeholders could benefit from being involved in real-world testbeds. The sample for this research shows that large firms and research institutions are most often involved in testbeds, while SMEs can struggle to get involved. The public sector could potentially take a stronger lead on some real-world testbeds to gain more socially beneficial innovation.
- Real-world testbeds are important to public sector actors due to their potential to support innovation and economic growth, develop better and more efficient public services, strengthen collaboration and make better use of existing infrastructure. For private sector stakeholders (innovators), the access to real-world environments is often essential to progress the product or process, as it de-risks commercialisation, provides evidence of their functionality and safety, and provides access to users and environments.
- An innovation process will often move in between the different innovation tools, depending on the learning obtained from testing. The example of UK Autodrive shows that different risk mitigations guided the choice of which testbed was required at what time, before moving to a real-world testbed.
- Real-world testbeds can be highly useful to the public sector, for example through de-risking procurement processes, as a tool for economic development, and as a framework for necessary collaboration with a range of institutions in the innovation ecosystem.
- For the private sector, real-world testbeds can provide vital access to environments where their innovation is intended to be used; they can facilitate learning and evaluation in a pre-commercial stage and provide the necessary evidence that makes commercialisation more convenient.

4 Why use a real-world testbed?

4.1 Introduction

The primary purpose of any testbed, regardless of whether it is in a laboratory or in the real world, is to test innovative products, technologies, services or processes. However, they are being used around the world to achieve a wide-ranging number of aims such as attracting investment, gaining competitive advantages, or making better and more efficient public services.

This section presents a framework of six different use cases to explain how real-world testbeds are being used and can be used in the future to achieve wider aims beyond facilitating testing. The framework provides information about the most common ways of using real-world testbeds, as well as guidance and lessons learned from established examples, aimed at those who plan to initiate or consider using real-world testbeds themselves.

4.2 Six use cases for real-world testbeds

This research – which involved expert interviews, workshops and analysis of a bank of examples (presented in Appendix 2) – identified six exemplar use cases for real-world testbeds, presented in Figure 5. The use cases are not necessarily exhaustive, and they are not mutually exclusive; Many real-world testbeds can be used by participating stakeholders seeking to achieve different objectives. For example, one stakeholder may use a testbed to capture a competitive advantage from a new technology (e.g. a nation wanting to become a world leader in a technology), while another uses it for 'local economic development and inward investment'. Accordingly, real-world testbeds are also tools for coordinating stakeholders in the innovation process.

Each of the identified use cases in the framework is presented in more detail in this section. The distinction between them is important, as they have implications for:

- How real-world testbeds are designed.
- Who could be involved.
- How they are organised.
- How they are funded.

A core challenge is to balance the many objectives involved, and to make informed decisions in the process of designing, setting up and running a testbed in a real-world environment.

Figure 5: Six use cases for real-world innovation testbeds

The following section describes common traits of each use case, which actors tend to be involved, and the implications this use case has for designing and managing a real-world testbed. Each section also presents a case study with lessons learned and focus elements. Full case study reports can be found in Appendix 2.

4.3 Testing innovation for verification and proof of concept

Testing and verifying the properties and functionality of new products, services, technologies or processes is a vital component of nearly any innovation. It is at the core of all testbeds, regardless of whether the environment is fully controlled, simulated or within the real world.

Description of the use case

Real-world testbeds are developed to be safe settings to ensure that innovations work as anticipated, solve a problem, establish the use case, and provide the intended benefits and outcomes for the target audience. The purpose of this tool always contains some form of testing innovation for verification and/or proof of concept.

Real-world testbeds often provide access to relevant stakeholders (such as citizens and potential customers) or the 'target system' the innovator seeks to enter (such as a public road or a hospital). Learning from the interaction of the tests and the target user or system is vital, as the tests can uncover mistakes, malfunctions, or raise questions that have not been previously considered. In turn, feedback from users can ensure more robust products and provide evidence of the functionality, safety, and usefulness of the innovation to support market deployment.

Verification and validation also provide the potential customer or user (for example a local authority or a public body) with essential information before making decisions regarding procurement, uptake, or investment. The evidence that comes from testing in the real world can contribute to de-risking procurement of new technologies or other innovations.

Typical actors involved in this use case

There are some actors to whom this use case is of specific importance or is more prominent.

- Private sector companies or research institutions that require validation and verification for technologies, processes or services before getting to demonstration stage or commercialisation stage.
- Public bodies or similar public stakeholders that require proof of concept before considering procuring or deploying an innovation.
- Sectors that have low accessibility entry-levels for innovators, or very strict standardisation barriers, such as rail industry and aviation.

Implications for design and lessons learned

This section provides some important lessons learned that could have an impact on the design of a real-world testbed specific to verification and proof of concept. The recommendations are drawn from literature review, insights from the bank of examples, and interviews.

Intrinsic knowledge of the technology and the system is required: Designing a real-world testbed aimed to verify proof of concept and the functionality of a technology requires close collaboration between those with knowledge of the environment it should be deployed in (e.g. a health system), and those with intrinsic knowledge of the technology (e.g. the artificial intelligence used to improve the health outcome of a specific patient group). This will ensure that the right questions are asked throughout the process and that the design of the real-world testbed can answer these.

Design with risk in mind: Along with the proof of concept and merely testing whether an innovation works as it should, it is important to design the real-world testbed based on which risks it needs to mitigate. The tester will need to manage which risks can be mitigated and ensure the residual risks can either be accepted or insured against. Testing will provide evidence that can make the innovation easier to commercialise.

Coherent evaluation standard across users: When evaluating the proof of concept or the validation of the innovation, it is important to use recognised and accepted criteria. This will help align the evidence gathered with the evidence required by the future customer or regulator.

Using real-world testbeds to test various uses of a new technology: Many emerging technologies, such as autonomous systems or IoT, can be used for a range of purposes. Testing such technologies in real-world environments can allow the tester to pinpoint in which areas of use the technology can best fulfil its potential. Such real-world testbeds would benefit from being designed with a higher range of flexibility.

Case study

Roboat – using urban canals to test use cases for autonomous vessels

Geography: Amsterdam, Netherlands

Facilitators: Massachusetts Institute of Technology (MIT) and Amsterdam Institute for Advanced Metropolitan Solutions (AMS)

Public stakeholders: City of Amsterdam, Waternet – the public water utility of Amsterdam).

Timeframe: 2017-2022

Description

This real-world testbed is part of a five-year research programme on autonomous floating systems ('Roboats') in Amsterdam, designing the world's first fleet (potentially) able to move people and goods, function as portable, temporary infrastructure, and gather data. Through testing the vessel in the canals of Amsterdam, the innovators were first able to verify that the technology – which had previously been tested in closed-off pools – functioned in the unpredictable environment of a lively city canal. They were also able to investigate how urban waterways in combination with the vessel can be used to improve city functions and quality of life.

Key success factors and lessons

- Proving safety and effectiveness supports testing and demonstrating in other cities.
- The real-world testbed showcased and improved control systems for autonomous navigation in urban environments and showed that new technology can revitalise 17th century infrastructure. The technology was first tested in Amsterdam before moving on to other similar canal and waterways cities such as Cambridge, UK, sharing the initial learning across the different urban environments.
- Use the real-world testbed to prove multiple uses and functions.
- The Roboat was used for a wide range of solutions to meet the city's and technology developer's respective needs. These include demonstrating technology such as 3D mapping of the urban infrastructure using artificial intelligence and 'laserscapes'; functioning as temporary bridge infrastructure; water quality and pollution data gathering; and clearing the canals of waste. This partnership of testing new technologies – many of which had additional public service use cases – allowed for verification of multiple technologies in close collaboration with public bodies such as the water company and the city council.

4.4 Local economic development and inward investment

Testbeds can be used by the public sector, inward investment organisations or business representative organisations (such as chambers of commerce) to market an area to investors, talent, and businesses, and support local economic development.

Description of the use case

When a real-world testbed is used for these purposes, it can, for example:

- Have a strong inward-investment component to attract firms to take part in activity in the area, and/or capacity-building for local firms.
- Be part of cluster-related policies, enterprise zones or other economic development tools.
- Be a tool to enhance local strengths, such as natural assets, skills or environmental conditions.
- Be used to attract talent.
- Reduce spending and risk of taking a chance on an innovation for the purpose of economic development.
- Lead to more innovative institutions through a better understanding of the innovation process and close collaboration with the innovators.

Using real-world testbeds for local economic development and inward investment is also useful for innovators. They often depend on access to real-world environments (e.g. roads, schools, care homes, or other publicly-managed or regulated spaces) to carry out their tests. Providing access to this infrastructure through real-world testbeds can open doors for firms in need of testing grounds, while simultaneously supporting the local economy through investment.

There are naturally risks to this approach and, like any other economic development policy, it requires planning and tailored approaches suitable to the place in question. There is a higher likelihood of benefiting from real-world testbeds if they are tailored to local challenges. The learning outcomes from a real-world testbed can provide intrinsic knowledge about the system that is tested (e.g. transport systems), and ways they could solve local economic challenges through innovative approaches. Involving local government and regulators can increase the chances of innovation being better fitted to solve local challenges.

Who initiates the testbed, and who else is involved: a section on the typical stakeholders

As a place-focused use case, the actors involved could include:

- Local, regional or urban authorities seeking to market their place, solve local challenges and drive local economic development.
- Economic development or inward investment agencies using testing in the real-world environment as a means to achieve their aims.
- Local institutions such as banks, Chambers of Commerce, Local Enterprise Partnerships (UK).
- Supranational institutions such as the European Regional Growth Fund can often be involved as funders of such activity to contribute to sectoral stimulation or economic development.

Implications for design and lessons learned

The approach for designing real-world testbeds for place-based purposes should be adapted to the local economic, social and environmental conditions as well as the institutions involved. The following recommendations are drawn from literature review, insights from the bank of examples, and interviews with real-world testbed stakeholders:

- Build potential real-world testbeds through focussing on locational advantages that could be attractive to innovators and investors. They will be attracted to testing in real-world environments rooted in a particular advantage.
- Real-world testbeds initiated by local institutions require the involvement of neutral specialists to enable fit-for-purpose design of testbeds that will benefit the place in question.
- To avoid potential 'lock-ins' into specific sectors, real-world testbeds could be open, flexible and able to respond to changing market demands. Choosing participants, sectors and technologies for a real-world testbed should be done in collaboration between local government and business, in line with local economic development strategies.

- If a company reaches out to use a place's environment for testing, local stakeholders should try to find ways that the testing activity can benefit the area. This can be secured in the design process and can lead to benefits of building local knowledge or supply chains.
- To increase the local benefits, the real-world testbed should seek to include local SMEs, not only the 'usual suspects' of large companies. This can contribute to more sustainable outcomes through capacity building and knowledge spillovers between actors.

Case study

Milton Keynes – a testbed for innovative transport solutions

Geography: Milton Keynes, UK

Facilitators: Milton Keynes City Council and various stakeholders

Timeframe: 2014 – ongoing

Description

Milton Keynes (MK) is the largest 'New Town' in England, founded in 1967 as a commuter hub situated between London, Birmingham, Oxford and Cambridge. The city council recognised that it needed to look beyond traditional transport solutions to keep up with population and jobs growth and to manage challenges of expanding the current road network and a dispersed housing pattern. To meet their future transport challenges and support long-term economic growth, MK's urban infrastructure has been made into a real-world testbed, including testing of:

- **An electric bus fleet**: A testbed aimed at delivering a clean and commercially viable electric bus fleet using inductive opportunity charging.
- **Self-driving vehicles**: The UK Autodrive consortium-based project, facilitated by a UK government-backed competition to support the introduction of self-driving vehicles.
- **City systems data management**: MK: Smart supports acquisition and management of data related to city systems such as energy, water and transport management.
- **Starship Delivery Robots**: Testing robots to deliver food and goods.
- **Lime Electric Bicycles**: Developing a dockless e-bike share scheme in MK's urban areas.

MK is not continuously operating as a testbed, but the city council uses the infrastructure as a testbed when opportunities arise. In addition, MK City Council recognises in their economic development strategy that the status of being a forward-thinking, smart city should be used to brand the city and enhance the sense of place. This could create a virtuous cycle of attracting firms to grow the local economy and using testbeds to solve the challenges of growth.

Key success factors and lessons

- Use real urban challenges to design testbeds: MK City Council has been focussed on choosing technologies and co-designing testbed objectives and environments to be in line with locally-specific challenges (as opposed to 'just' opening the urban environment for any kind of technology). Interviewees claimed this ensured benefit for Milton Keynes and mitigated risk of not gaining such benefits.
- Attract technologies based on local strengths: The council is attracting testbeds that use their unique assets. For example, with a more recently designed road and footpath system, autonomous pods and delivery robot testing has been easier to carry out. The city further plans to use the proximity to an Amazon distribution centre and a university with a world-class aeronautical faculty to test the use of drones in the city.
- Use real-world testbeds to improve the city: Through co-designing the properties of the real-world testbed – what the innovators should test in an area – MK has learnt valuable lessons not otherwise possible to anticipate through the testbed activity. For example, the autonomous pods were set to try to solve a particularly congested area. This has influenced the anticipatory planning of a transport system fit for the future.
- Real-world testbeds can ease budget constraint challenges for public services and infrastructure: Procuring unproven technologies can be both risky and expensive. The MK approach has been to provide some of its available urban infrastructure for testing. In return, companies get to verify their products and develop their business case, which is less risky and costly than directly funding such a solution.
- Using the 'brand' of being a city open for testing to attract investment and activity: MK has built a reputation as a city open to testing as a direct result of the real-world testbed activity. This can be seen through media narratives and an increased number of businesses reaching out to the council. This reputation, along with the networks from previous projects, has led to companies seeking out MK as a location for further testing and investment – a proactive inward investment strategy.

4.5 Creating an appropriate regulatory environment

Technological change often outpaces the regulatory frameworks by which technology and businesses are governed, creating issues for proper regulation, protection of rights and law enforcement. Real-world testbeds can involve regulators to support change in line with technology. Real-world testbeds also allow regulators themselves to test different approaches to regulation, learning and evaluating different effects as the testing progresses. This section is about using real-world testbeds for the purpose of creating appropriate regulatory environments through temporary changes in bounded areas such as experimentation clauses and special permits.

Description of the use case

The demand for more agile regulation is increasing due to the rapid acceleration of new, ground-breaking technologies.[18] Regulatory mismatch can occur if technological advancements move at a faster pace than the regulation. This is often the case with technologies such as drones, data use and artificial intelligence.

The format of testing regulation in a real-world testbed context provides several benefits. real-world testbeds aimed at creating appropriate regulatory environments can:

- Ensure involvement of regulatory bodies at an early stage rather than ad-hoc.
- Provide an opportunity for regulators to test different approaches to regulation in a secure environment, collaborating closely with innovators. This also builds necessary expertise within the regulatory body in question, which is necessary to provide safe and appropriate regulation.
- Design a manner of regulations that incentivise innovation while still assessing risks and ensuring safe implementation.
- Allow regulators to see the potential effects of an innovation in the real-world environment or with its intended users, increasing the probability of more appropriate regulation.
- Be used to test regulation on technical innovation, process innovation and the use of new business models to deliver services.
- Build trust and increased understanding between innovators and regulators.

Main actors involved

Depending on the innovation, the actors involved can be:

- The relevant regulatory bodies for the innovation in question, for example the Civil Aviation Authority (CAA) in the UK related to testing of drones.
- Relevant governmental bodies responsible for the sector/cross-sectoral approach;
- International regulators such as relevant EU bodies.
- Local authorities in the location of the testbed with regulation on the local level such as local plans, transport regulation and other devolved responsibilities.
- Large and small innovators operating in the testbed.
- External technology experts, for example from universities and research institutes.

Implications for design and lessons learned

Based on interviews with experts and real-world testbed practitioners, this section presents some important elements to consider for this use case:

- When testbeds involve regulatory bodies, it is important to **build a trusting environment**. With a high level of trust and clear guidelines, testbeds can be 'safe spaces' that offer mutual understanding of each other's perspectives and knowledge through dialogue and co-design, as well as the ability to ask questions.
- Creating a structured manner of collaboration is crucial to allow an iterative process with many stakeholders such as policy labs (see section 5.7 for more detail).
- It is important to allow for **sufficient time and to identify the suitable ways of working** so that regulators can be involved and contribute to the process. Regulators may not be accustomed to working iteratively and flexibly, and innovators may need to be more patient than usual, respecting the level of knowledge required to ensure safe implementation.
- 'Regulators' can also be local authorities with specific devolved powers, or international bodies. It is important also in this case to allow for co-design, thorough risk analysis and collaborative methods.

Case study

Cross-border testbed to test Connected and Autonomous Vehicle (CAV) regulation[19]

Description

In April 2019, France, Germany and Luxembourg opened the cross-border testbed for autonomous vehicles. The environment involves a 206 km circuit between Schengen, Saarbrücken and Metz, allowing for a wide range of digital technologies to be tested for CAVs under real-life, cross-border conditions. It is backed by partners from industry and regulation in the EU and the respective countries.

The goal of the real-world testbed from a regulatory perspective is to:

- Facilitate a joint exchange of experience based on experiments, results of industry and academia, especially regarding judicial and technical issues encountered during the testing.
- Identify challenges related to traffic management and safety impacts, interactions with infrastructure, and the generation, processing, storage, dissemination and exploitation of data for CAVs.

Lessons learned

Coordinating with other countries will save costs and increase benefits: Large-scale real-world testbeds are costly and complex. In the case of the highly integrated border system facilitated by the EU, sharing knowledge, risk and costs is highly beneficial for all stakeholders involved. Not only does it make the experimentation cheaper (and thereby perhaps easier to accept from a tax payer's point of view), it also facilitates integrated thinking in an integrated traffic system.

Organising process to consolidate objectives and aims – but based on the regulatory perspective: The real-world testbed was initiated by public authorities. The aims, priorities and thematic test areas were established by national, federal, regional and local authorities in the participating countries. It was later subjected to scrutiny and challenge by industry and academia to establish a consolidated set of testbed priorities.[20]

Real-world testing provides concrete use cases for analysis: The regulatory bodies which initiated this real-world testbed recognised the opportunity to explore the approach to regulating AVs in a less abstract manner through a real-world testbed. Some aspects of introducing disruptive technologies is challenging to imagine through scenarios and conversations, so seeing AVs 'in action' can bring these issues to the surface at an earlier stage, enabling a more appropriate regulatory response.

Maximising learning through designing a multi-purpose testbed: The Digital Motorways testbed does not simply consist of a strip of road; it encompasses different categories of road, from motorways to more rural settings. This takes into consideration the varieties of contexts where AVs may be used and highlights the multiple challenges that may occur from different use cases.

4.6 Make public services better and more efficient

Innovation such as emerging technologies can have profound effects on delivering better and more efficient public services. It can also pose a challenge to integrate the most useful technologies due to risks (perceived and actual), lack of knowledge and lack of evidence of the effect to prove the business case. This use case is about real-world testbeds for the benefit of public services.

Description of the use case

In most areas, public services[21] such as health and social care, transport, education and energy provision have potential for increasing the uptake and spread of innovative measures across the delivery of public services. Using real-world testbeds to achieve this can:

- Reduce the risk of procuring technologies that are not fit for purpose.
- Include public service end users (such as patients or passengers) in the testing to understand the effect the innovation has on them and their experiences.
- Ensure safe and controlled access to users (and often their data), public professionals and systems for innovators, reducing barriers to innovation in the public sector.
- Ensure an evidence-based approach to spreading innovation across systems or public bodies.
- Break down barriers for collaboration between the private and public sector.
- Capture the learning from being involved in the innovation process, potentially contributing to cultural or institutional change and more openness to innovative solutions within public service bodies.

Real-world testbeds also allow public and social infrastructure (such as hospitals, schools or roads) to be better utilised for innovation purposes. It can be challenging for private firms to gain access to such systems to develop and test products or processes that benefit these services.

In the face of rising public service costs and/or budget cuts, testbeds can safeguard and improve high-quality public services. Testing can prove whether the innovation reduces costs, increases local revenues, improves service delivery, improves outcomes or reduces risks compared to existing services or technology.

Main actors involved

Using real-world testbeds to make public services better and more efficient usually includes some of the following actors:

- Government departments and other public bodies seeking to innovate in their area of responsibility.
- Regulatory bodies if required, often ensuring ethical considerations such as privacy and other sensitive issues.
- Public service providers at the local level.
- Public service users and/or their data concerning specific public services.
- Innovators with suitable solutions needing to test and validate their product, process or service in the environment where it is intended to be used.

Implications for design and lessons learned

When designing real-world testbeds for improving public services and making them more efficient, the following aspects are important to consider in the design process:

- As real-world testbed activities are often additional to public servants' day-to-day jobs, it is key **to involve individuals who are passionate about implementing innovation and change**, otherwise the testbed may struggle to see results.
- As evidence is particularly important when dealing with public services, **designing a good, unbiased evaluation process** is key to obtaining the best possible evidence. See Section 5 for more detailed guidance on this.
- As real-world testbeds for public services are often tested in one place and meant to spread across larger infrastructures (for example from one school throughout an educational system), **finding agreed measurements and criteria for success in evaluation** is also important.
- There are often several stakeholders with different ways of working involved in these real-world testbeds. **Getting objectives in line** has been noted as vital to ensure everyone pulls in the right direction. The time it takes to achieve this should not be underestimated.
- There are often **ethical considerations and risks** connected with real-world testbeds dealing with public services and use of citizen data. This needs to be discussed with regulators and anyone involved in the real-world testbed as users. Data and information management plans should be part of any trial or real-world testbed.

4.7

Case study

NHS testbeds – using testbeds to make health services better and more efficient

Geography: England

Facilitators: Department of Health and Social Care, Office for Life Sciences, NHS England

Timeframe: 2016 – ongoing

Description

The primary purpose of the National Health Service (NHS) testbeds in the UK was to improve services delivered by the NHS and make them more cost efficient through using technology. It was also important for the programme to contribute to changing the culture of innovation within the NHS – a large public sector organisation, which by nature can be difficult to drive and implement innovation across services.

The programme is organised into 'waves', each lasting two years, to enable learning and evaluation along the way. The first wave commenced in 2016 and included seven testbeds across England with 40 innovators and over 250,000 patient participants. The technologies tested included predictive algorithms to manage patients at risk of developing conditions, aggregation of data to improve clinical decision-making, and technology to monitor risk of crisis in clinical pathways at individual homes or care homes. Testbeds brought together partners of senior government officials, academia, industry, patient groups and charities.

Key success factors and lessons

- Evaluation is a fundamental part of the testbed: A thorough evaluation provides robust evidence of what works well and areas of improvement across core objectives. The NHS evaluated whether the intervention improved patient outcomes, lowered health care costs and supported partnerships. Evaluation was necessary to create evidence that eased the process of potentially adopting the innovation across the NHS nationwide, and enabling improvement of the process itself in future waves of testbeds. A handbook was created for further learning from Wave 1.
- Ensure an evaluation plan: An evaluation plan to be implemented by quality personnel was required when partners applied to join the testbed. Qualified personnel were often external, to avoid bias in the evaluation.

- Make learning easy: Structuring the testbeds into two-year waves allowed the learning from the first wave to be implemented into the second wave. Handbooks for data management and evaluation were amongst the tools created to ensure that lessons learned were disseminated and incorporated.
- Finding and coordinating the right partners and collaborators takes time: Setting up the testbed took longer than anticipated, both from the private and public sector point of view. The following elements were identified as particularly time-consuming: i) getting the core team in place, ii) determining terms of collaboration and shared objectives, iii) information governance and decision-making, and iv) testing and evaluation.
- The importance of quality of leadership and ownership: Finding local bodies with individuals who were sufficiently engaged and interested in implementing digital technologies was core to the success of the testbeds. Ensuring quality of leadership with experience and resources to fully engage with the testbed was also essential. Testbeds chosen without fully fulfilling this criterion struggled the most.
- Clarify and reconcile the (often competing) aims of stakeholders: With a range of stakeholders from diverse sectors involved, competing objectives were an issue. While the firms aimed to access data and verify their products, others wanted to use the testbeds to incentivise SME innovation, or help local NHS bodies, with little tradition of R&D work, 'catch up'. It was vital to clarify which aim was most important and stick to it throughout. Managing the number of stakeholders and number of technologies tested supported clarity of the aims.

4.8 Addressing market failures and solving grand challenges

Real-world testbeds can be used to incentivise economic activity or steer innovation in directions that respond to challenges which the market does not necessarily solve on their own. This use case is about addressing market failures and solving grand challenges.

Description of the use case

Both market failures and grand challenges represent a broad range of issues facing society. On the one hand, testbeds of all levels can be used to solve market failures and challenges on the supply side, such as lack of R&D[22] investment in private companies. To this end, publicly (or otherwise) funded testbeds can incentivise R&D activity across different firms, leading to more innovative activity and investment-ready firms.

Testbeds can also be used to incentivise development and testing of solutions to 'grand challenges' or 'moonshots': important national or global problems not being pursued (or not being sufficiently pursued) by actors in the market. Typical 'grand challenges' of our times are responding to climate change through renewable energy, capturing carbon, or changing transport options and behaviours.

Using real-world testbeds to achieve responses to market failures and grand challenges can:

- Contribute to creating demand for products and solutions that represent better alternatives to what the market currently offers.
- Be used as a tool to respond to lack of risk capital being invested in unproven technologies – government funding can share the risk of investment with the private sector through real-world testbeds.

- Incentivise more socially and environmentally-beneficial innovation activity, through earmarked investments targeting specific sectors or aims.
- Facilitate collaboration between sectors, academia and relevant institutions being incentivised to achieve specific aims.
- Provide incentives to invest and carry out more testing of innovation by the private sector, potentially improving the business case for investments in otherwise uncertain and unproven technologies.

Key actors involved

The actors involved in this use case will naturally vary, based on the exact nature of the testbed purpose. Generally, actors can be:

- Public and private research institutions aiming to solve grand challenges or commercialise products.
- Institutions responding to market failures on regional, national or supranational levels.
- Start-ups and spin-outs from universities.
- Private sector companies, NGOs, philanthropists, or non-profit organisations seeking to solve grand challenges.
- Financial institutions or investors, either oriented towards solving specific challenges or more mature business cases.
- Public agencies or innovation agencies seeking to incentivise innovation or R&D investments in general, or within a problem segment or sector.

Implications for design and lessons learned

The implications for design and the establishment of these real-world testbeds is dependent on the nature of the specific purposes. There are, however, some overarching lessons and implications worth considering for those aiming to use testbeds for these purposes:

- Both when designing to mitigate for market failures and/or grand challenges, the products and processes tested often have no guarantees of success. It can be difficult to balance the priorities between choosing the right technology to test and staying flexible and responsive to changes in the market. **Real-world testbeds should bring in market experts to assess competing technologies as well as the market response**.
- Real-world testbeds involved in solving market failures or grand challenges both require cross-sectoral and/or multi-stakeholder approaches due to the complexity of these issues. Like other real-world testbed use cases involving multiple actors, **allowing sufficient time to align aims, develop working methods and build trust is crucial for success**.
- **This use case requires a common understanding of the long-term horizon of results**. Grand challenges and market failures are seldom a 'quick fix', and success is often dependent on patient capital and space for mistakes or wrong directions. Communicating progress frequently, transparently and effectively to involved stakeholders is key to building the required patience and understanding.

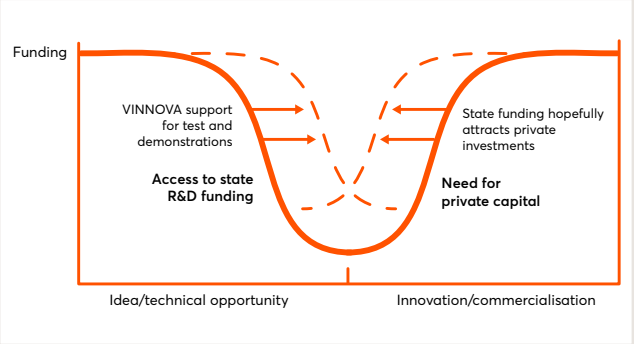
Case study

Testbeds in Sweden – a national strategy responding to multiple challenges

Geography: Sweden

Facilitators: The Swedish Government, The Innovation Agency Vinnova

Timeframe: 2016 – ongoing



Description

The national strategy 'Testbed Sweden' was set up to provide a common framework across Sweden, coordinating the many existing test and demonstration facilities across the country. Some of its aims include to: coordinate existing testbeds better and establish new facilities that can solve challenges for society; engage and facilitate opportunities for SMEs to test their products and processes in a real-world environment despite lack of resources; and narrow the 'valley of death'[23] for firms, caused by the lack of risk capital and decrease in business R&D investments (as a percentage of GDP).

Key success factors and lessons

- A coordinated network of testbeds can contribute to solving complex challenges: Countries across the globe are likely to already have a range of testbeds operating individually. Coordinating them into networks, both nationally and internationally is, according to the Swedes, necessary to solve the many complex challenges facing modern society. The Swedish National Testbed Strategy aims to facilitate better coordination between the many individual testbeds operating across the country. Having them operate as an integrated system is meant to enhance the quality of each testbed, increase the number of innovators using the testbeds, and improve Sweden's opportunity to market the country with an 'innovation supply-chain'. They are also looking to integrate them into a European system of testbeds.
- Public investment in testbeds can contribute to closing the funding gap for innovative firms: Testbed Sweden is partly developed to close the widening 'valley of death' for firms. As the picture above depicts, the theory states that public funding and coordinating testbeds will incentivise firms to bring their ideas and technical opportunities closer to successful commercialisation. This progress then incentivises private capital investment when the technologies are more mature, narrowing the valley where many innovators struggle.
- Engaging SMEs in testbeds is challenging: A challenge of many testbeds in Sweden has been to support SMEs to participate. SMEs often struggle with resources to be able to test their technologies and commercialise their innovations or access testbeds if they are

not customised. Some testbeds are providing access to expertise and wider mentoring and business development advice, although they are still rare.

Testbeds are a critical part of the innovation and commercialisation process: The Swedish Government is convinced that investing in testbeds supports economic growth of the country by being open and providing the right environment for investors. It is recognised as an integral part of the innovation system, allowing innovators to advance their solutions in a secure environment. An evaluation of testbeds within health and social care has shown that several tested innovations have gone on to implementation, while others have been identified as less mature. Interviewers also claimed that testbeds contributed to better coordination of private and public stakeholders, one of the key aims of the strategy.

4.9 Capturing competitive advantages from frontier technologies

With the speed of advancement within new segments of technology, opportunities to solve problems in innovative manners open on several levels. Regions, nations and institutions can gain competitive advantages through facilitating for testing and implementation of such technologies. This use case illustrates how to best capture these advantages.

Description of the use case

The Fourth Industrial Revolution is defined by technological breakthroughs such as artificial intelligence and machine learning, robotics, 3D printing and the Internet of Things.[24] They offer a multitude of opportunities to reimagine how we approach tasks and systems. These types of technologies have paved the way for innovation in the realm of into 'waves', each lasting two years, to enable CAVs, smart city technology, and a range of automated services previously carried out as manual tasks.

Technologies such as these are dependent on being thoroughly tested in real-world environments to ensure (amongst others) safe operations, functionality, usefulness and citizen acceptance. Real-world testbeds are crucial tools to achieve such testing, and the areas facilitating it can in return achieve competitive advantages. Real-world testbeds operating in this realm can:

- Ensure relevant systems are developed and prepared for the next wave of technological advancement, being ahead of the wave instead of lagging behind.
- Represent both national strategic opportunities for future development and/or commercial opportunities for relevant sectors or firms.
- Capture first-mover advantages for stakeholders involved.
- Coordinate the necessary stakeholders through a testbed to foresee potential issues and challenges of implementing the technologies.
- Allow users to participate in the testing, which also leads to familiarisation with the technology and direct feedback and learning.
- Facilitate collaboration between large and/or foreign companies seeking real-world testing environments with local firms and SMEs, which could potentially lead to knowledge spillovers.

Key actors involved

The core actors involved when using real-world testbeds for capturing competitive advantages of frontier technologies can be:

- National or supranational governments or institutions seeking to gain advantages.
- Internal test experts (testers) and external stakeholder (advisers) technology experts.
- Relevant regulators (often more than one).
- Economic development agencies or similar institutions.
- SMEs and large companies.

Implications for design and lessons learned

Based on interviews with experts and relevant real-world testbed practitioners, the following design implications and lessons learned can be drawn:

- Real-world testbeds developed for this use case are often large-scale infrastructure or projects with similarly large costs **suitable for large partnerships and collaborative funding**.
- As this use case explicitly deals with (often) large-scale new technology, it will **almost always require regulatory adaptation and thereby collaboration with regulators** at an early stage of the design process. Designing real-world testbeds to allow for regulatory testing can add to the benefits, as there are no definite answers regarding how to regulate new technology.
- **The real-world testbed will be stronger if it involves the end user/potential customer of the technology** from an early starting point, to work with attitudes and adaptation to preferences.
- Large-scale technological opportunities often require **long-term funding and sufficient time** to allow for progress and results. Patience in results and capital is important.
- **These types of real-world testbeds are often suitable at a global scale** – attracting particularly good research environments and large companies with capacity to innovate at this level.

Case study

Smart Santander – facilitating a competitive advantage for IoT technologies in cities

Geography: Santander (Spain)

Partners: European Union Future Internet Research and Experimentation, City of Santander, Santander Local Economic Development Agency, 25 partners from across Europe and Australia

Timeframe: 2010-2014

Description

Smart Santander was an Internet of Things (IoT) testbed operating across Europe from 2010-2014. At the time, it was the most extensive urban IoT infrastructure in the world, comprising thousands of sensors communicating with the deployed IoT architecture. IoT is and was a frontier technology with big rewards for the first cities and firms that could crack the technology and its uses. This case study focusses on the city of Santander in Spain, where they deployed 12,000 censors across the city for various purposes. The testbed facilitated testing of approaches to and building blocks of IoT architecture, and the interaction with device technology and their use in delivering public services.

Key success factors and lessons

- Testing in a real-world environment allowed for better research and collaboration: The real-world environment provided a more practical approach for researchers, allowing them to learn and improve products quickly. It also facilitated collaboration between research institutes, citizens and private sector actors, creating a framework for more rapid development of the IoT technology that has moved beyond the testbed phase. The number of sensors deployed across the city increased from 12,000 during the testbed period to over 20,000 that are now used in day-to-day management of the city.
- Involving citizens boosts credibility and adaptation levels: As citizens were brought along on the journey of embedding sensors within the city using the services during testing stages, it allowed for a status change from 'testing' to 'operational' following the testbed period. The public continued to use the technology in their daily lives. A survey carried out by McKinsey showed that the citizens of Santander were both aware of the sensors across the city, and highly satisfied with the services they contributed to.

- Clarity of purpose is key to innovating ahead of the wave: The purpose stated by the Smart Santander project was two-fold: 1) to facilitate real-world experimentation of IoT technology to achieve a leading role for European cities in IoT technologies, 2) to provide useful services tailored to the cities during the testbed operation. It has also achieved the aims set by the EU, one of which was to 'achieve a leading role in Europe in the IoT technologies'. The European Commission stated that "The project has successfully achieved all its objectives, even exceeding initial expectation."[25]
- Patience and scale are necessary to gain real advantage: To achieve the competitive advantages on a supra-regional scale (as envisioned by the EU), the testbed area(s) require adequate scale, length of time to allow learning and improving, well-run partnerships with win-win outcomes, and sufficient long-term funding. Funding was also spread over several aspects of the IoT, reducing the risk of investing in 'future trends' and facilitating learning between projects.
- A successful testbed can lead to changes in the economic environment: Santander, originally a heavy service economy, has seen the smart city investment enabling a revitalisation of the business and entrepreneurial ecosystem. This is also due to an integration of the smart city project into the municipality's strategic plan, the masterplan for innovation, and the Smart City Plan. Santander is now, according to McKinsey, among the top ten strongest cities in Europe regarding their smart technology base, better than Berlin, Paris and Moscow.

5 Designing real-world testbeds – things to consider?

Real-world testbeds are increasingly popular and are frequently considered by local and national institutions with various motivations. For real-world testbeds to be successfully set up or run by stakeholders such as national and local governments, it is essential to understand how to best design the real-world testbed to achieve their respective aims and objectives. This section outlines eight critical considerations for any stakeholder, private or public, seeking to establish and design successful testbeds in real-world environments. It is informed by findings from literature, lessons learned from case studies, and interviews with experts and real-world testbed actors.

5.1 Clearly define the purpose – and whether a real-world testbed is the right means to achieve it

Although obvious, a clearly defined purpose with achievable and measurable objectives is imperative for a successful real-world testbed. There are often a wide variety of stakeholders involved in real-world testbeds who might have different, sometimes conflicting aims for participation. If such aims fail to be prioritised or clarified, it may harm the outcome and make the real-world testbed harder to govern. Aim for simplicity, clarity and a hierarchy of objectives early in the design process. As the purpose gets clearer, ask the question of whether real-world testbeds are the right tool.

Clarifying what any intervention aims to achieve is vital in any investment, particularly involving spending public money. Although seemingly obvious, most real-world testbed actors involved in this research underlined the importance of clear objectives. real-world testbed aims are often too broad, making measurement of success and design of testbed requirements challenging.

When Milton Keynes City Council made their infrastructure available to testing autonomous vehicles, they ensured that the aims were specific to local challenges. Instead of having a general aim such as 'we want to test the use of autonomous vehicles in the urban environment', they required that the testbed should contribute to solving local traffic challenges such as a specific congested area or a crossway with high frequency of collisions. By asking more specific, local questions of the real-world testbed, the council were guaranteed valuable outcomes and lessons learned from the presence of Autonomous V, alongside the innovators and regulators involved.

Recommendations

- Ask the questions 'Why do you want to establish a real-world testbed?' and 'What do you seek to achieve with it?' The answers to these questions will also better inform the decision of which tool to use and whether a real-world testbed is the most suitable option.
- Different stakeholders will have diverse objectives; ensure that they do not conflict, prioritise objectives rigorously and ensure that the key actors have a common understanding of these priorities. This process can take time and should not be underestimated.

Key resources

Design implications from the use cases in Section 4.

5.2 Collaborate with the right stakeholders and ensure coordination

Real-world testbeds can be tremendously useful to break up silos and unite stakeholders across various institutions required throughout the innovation process. A real-world testbed can, for example, include national and local government, innovators, citizens, regulators and researchers. In the design process, it is essential to consider which stakeholders will add value to the real-world testbed in question and when they should be involved. We recommend not underestimating the time it takes to coordinate these actors and establish common ways of working, building a clear line of decision-making and avoiding 'too many cooks'.

Most testbed experts and actors who contributed to this report mentioned the importance of taking time in building the testbed team. First, partners need to find the right team combination and build trust amongst the team members, and second, they need to agree on working methods and facilitate agreements on intellectual property rights and other sensitivities.

It can be tempting to include a wide range of stakeholders in a testbed, as many could potentially contribute with knowledge, financial resources or other capacities. This tends to be a balancing act, where simplicity is often key to success. One of the partners in the Testbed Sweden strategy, Tilvaxtanalys, stated:

> "When a specific task and few stakeholders characterise a project, the implementation was fairly easy to manage as both the testbed operator and the stakeholder tended to better understand their role in the project. More complex and stakeholder-rich projects can be subject to more severe challenges involving coordination and administration."

Future users of the tested technology are important stakeholders who should not be forgotten in the development of a real-world testbed. Public acceptance is a key ingredient for the 'real world' element of the testbed. The public need to interact with the testbed and understand its aims. Because of this, all other stakeholders need to have a common message for the public and to engage them at an early stage.

Recommendations

- Create a broad stakeholder map of who might be involved in the real-world testbed. Follow the steps of identifying relevant stakeholders, analysing their perspectives and interests, mapping the relations between the team and other stakeholders, and prioritise their relevance.
- Avoid 'too many cooks' unless the capacity of the real-world testbed is designed to handle it. Use the objectives and purposes to ensure that any participant contributes toward accomplishment.
- Ensure quality of leadership and passionate individuals with capacity to engage with the testbed activities throughout the given period.
- Ensure a suitable organisation, a good framework of collaboration, a clear decision-making strategy, and clear division of responsibilities.
- Where possible, involve citizens or users in the real-world testbed. Of the real-world testbeds interviewed that did this, they underlined its added value to the investment and a much easier road to implementing and disseminating the innovation after the testing process.

Key resources

Stakeholder engagement tools, for example: www.bsr.org/reports/BSR_Stakeholder_Engagement_Stakeholder_Mapping.final.pdf

5.3 Organising and funding the real-world testbed appropriately

Organisation and funding of a real-world testbed can be conducted in many ways. The testbed can be formal or informal, long-term or short-term, and run as a business or a private-public partnership. A conscious decision needs to be made related to the context in question. We recommend looking to similar testbeds, not over- or under-funding, taking a step-wise approach, and seeking to maximise the output.

Real-world testbeds are diverse. Some are 'formalised' as continuously available and specialised environments, for example in Norway, where a real-world testbed continuously offers a piece of the fjord to innovators who wish to test autonomous shipping technology. Others are more 'informal', for example the testing of transport technology in Milton Keynes. They are open to innovators approaching them to request using the urban environment for testing, however only the projects that are deemed most beneficial to Milton Keynes are 'let in'. Other real-world testbeds can be run like a business, with employees running the facility, testbed customers (the innovators), and capacity management.

In terms of funding, real-world testbed costs vary widely, depending on the scale and maturity of the innovation that is set to be tested. Whether short-term or long-term funding is required should be aligned with the purpose and objectives. The real-world testbed may be relatively inexpensive if the real-world testbed is short-term, if the innovator carries much of the cost, if the technology is highly mature, or if using the environment is inexpensive.

More uncertainty is associated with the real-world testbed if the purpose relates to, for example, introducing disruptive and/or less developed technologies or deploying them in complex environments. Achieving such aims often requires more patient funding, which allows flexibility in design and learning from experiences along the way.

There are different examples of funding models. Testbed Sweden is a national programme funded through the national budget to facilitate testbeds and innovation around the country, based on the Industrial Strategy. The NHS testbed programme was a centralised pot of funding that potential participants were able to bid for funding. And, in the Singapore Autonomous Vehicle testbed, the private sector funded the cost of the testbed equipment and design, while the public sector provided access to the environments.

Recommendations

- Seek the appropriate funding linked closely to the aims and objectives of the real-world testbed in question.
- If public money is part of the funding mix, there should be requirements attached that secure public benefits.
- If the real-world testbed seeks to enable testing of disruptive technologies or solving grand challenges, funding needs to be sufficiently patient.

Key resources

Funding strategies such as:

Deloitte Smart Cities Funding and Financing Strategies: https://www2.deloitte.com/us/en/pages/public-sector/articles/smart-cities-funding-and-financing-strategies.html

How to develop a funding model: https://ssir.org/articles/entry/finding_your_funding_model

5.4 Analyse risk and embed in real-world testbed design

Innovation that requires testing in real-world testbeds is associated with various levels of risk, be it related to health and safety, usefulness, finances, regulation or sustainability. Whatever the innovation tested, it is imperative to assess the potential risk of testing in the real world and introducing it to the market. The real-world testbed provides an arena to build evidence of risk mitigation and should directly influence the real-world testbed requirements, and thereby the design. We recommend strict review that previous testing has been carried out, a wide range of experts to ensure risks are identified from various perspectives, the use of rigorous methodologies, and robust evidence before giving the 'all clear' for commercialisation.

The level and nature of the risks are naturally reliant on the purpose, the traits of the product, and the environment in which the testing is taken place. For example, one of the NHS testbeds introduced new technology for self-management of diabetes patients, which poses different risks to testing financial technology or clean energy in a local energy system.

Whichever innovation is proposed to be tested in a real-world environment requires a strict standard that it is sufficiently safe. A risk register is required to understand what can go wrong and the mitigations provided to avoid this. Several safety-critical risks must be proven mitigated before tests can be carried out in the real world.

A risk assessment and mitigation register can also determine the requirements of the real-world testbed's design. For example, a drone that is meant to deliver blood samples from one hospital to another needs to be able to test that the drone can navigate to the right address, not damage the sample, deal with obstacles and handle various weather conditions. A well-designed testbed should include the infrastructure to test these elements and provide evidence that risks associated with this are either fully mitigated, low enough to be acceptable, and are insurable. This ensures technologies can be safely introduced into the market.

There will always be residual risks that are not possible to mitigate fully, even in a well-designed testbed. However, someone still needs to accept the residual risks, which can seem off-putting to many institutions uncertain about new technologies. UK Autodrive, the programme testing autonomous vehicles, worked with insurance companies with wide-reaching experience of risk assessments to understand which risks they would be able to accept. This is an approach recommended in other testbeds as well.

Recommendations

- Involve a broad range of experts to create a risk assessment and mitigation register covering risks related to health and safety, finance, regulation, operation, technical issues and public perception.
- Ensure that the innovation is safe enough to operate in the real world, e.g. that safety-critical elements have been tested in laboratories or closed-off environments.
- Ensure robust methodologies for risk assessment and mitigation are utilised.
- Use the risk and mitigation register to inform the real-world testbed design, what the real-world testbed is required to be able to test and provide evidence for.
- If necessary, work with insurance companies or similar institutions to discuss which residual risks can be deemed acceptable.

5.5 Embed evaluation early

Evaluation is a core necessity of any real-world testbed to understand both the impact of the innovation and the outcome of the process. Too few testbeds are robustly evaluated, leading to loss of important learning and evidence. It is imperative to start any form of evaluation early and ensure a baseline of the current environment before the intervention is introduced. Although there is no 'one-size-fits-all' approach to evaluation of impact or outcome, there are a range of supportive frameworks available to guide various approaches.

Evaluation is a necessity in testbeds to understand how the processes and technology affected its outcomes. Process evaluation relates to understanding how different implementation processes affect the successful outcomes of the technology. Conducting process evaluation can be just as important as outcome evaluation, as certain aspects of implementation could affect replicability of safe and effective use of the technology in demonstration or commercialisation phases.

To understand the impact of innovation in process, product or policy, testers need to compare the outcome of the innovation with what would have happened anyway. This is usually not straightforward because what would have happened is almost impossible to know for sure. There are often many factors at play at once, and this can complicate simple comparisons. Can the tester be sure that an observed change is because of the action they took (in this case: the innovation)? Or is some other factor responsible for part of that change? The further testers move from a controlled test environment, the harder it can be to be sure of causality.

The most important first step in testing impact is to be clear about what it is that must be measured. Sometimes this will be the direct output: "Were patients served more quickly or cost effectively?"; "Did people travel in our autonomous vehicles safely?"; "How many businesses took advantage of new smart technology opportunities?" In this case, causality is less in question.

To understand outcomes and impacts more broadly, testers need to establish what would have happened anyway: "Did patient outcomes improve?"; "Was there less congestion in the city centre?"; "Did firm level productivity increase?"

Accepted methods for establishing causal impacts include a wide range of techniques. The 'gold standard' is randomised control trials, which are quasi-experimental approaches which exploit elements of randomness in timing, allocation or placement. But simple difference-in-difference based approaches are also helpful: these either define a comparison group or use regression techniques to control for the other factors that might simultaneously influence change.

Recommendations

- Start early. Familiarise yourself with and decide the method that will be adopted and the scope of the evaluation.
- Identify the right, unbiased evaluation team. Ensure they have a sustainable governance of evaluation throughout the testbed process. Some real-world testbeds may consider procuring evaluation from an external actor, or collaborate with researchers.
- Identify the right questions to ask and collect the necessary data before the intervention, so there is an established baseline for comparison.
- Ensure that the outcome of the evaluation is agreed as a good enough standard to further deploy the innovation if deemed to have positive impact (for example, across a health system, across necessary geographies, etc.).
- Spend time thinking about whether the comparison method you have established is appropriate – are you comparing 'apples with apples'? This is a matter of common sense and knowledge of the specific policy and locality rather than of mathematics.
- Identify and collect the learning from the evaluation in a succinct manner and ensure good dissemination is in place to ease the spread of evidence to the right actors.

Key resources

The NHS testbed evaluation handbook has an overview and description of the various methods used for evaluation, as well as a full overview of the evaluation process: https://www.england.nhs.uk/wp-content/uploads/2018/11/test-beds-programme-evaluation-learning-from-wave-1.pdf

The 'How to Evaluate' section with the What Works Centre for Local Economic Growth (WWCLEG) is very useful to better understand methods of evaluation:

- **What to Evaluate**: https://whatworksgrowth.org/blog/how-to-evaluate-what-to-evaluate
- **Define Success**: https://whatworksgrowth.org/blog/how-to-evaluate-define-success
- **Start Early**: https://whatworksgrowth.org/blog/how-to-evaluate-start-early
- **Get Everyone on Board**: https://whatworksgrowth.org/blog/how-to-evaluate-get-everyone-on-board
- **Plagiarise**: https://whatworksgrowth.org/blog/how-to-evaluate-plagiarise
- **How Long**: https://whatworksgrowth.org/blog/how-to-evaluate-how-long
- **Collect Data**: https://whatworksgrowth.org/blog/how-to-evaluate-collect-data
- **Find a Control Group**: https://whatworksgrowth.org/blog/how-to-evaluate-find-a-control-group

5.6 Market your testbed and include the right innovators

Regardless of how the real-world testbed is organised, there are a range of innovators that can be involved. However, as the bank of examples shows, large and resourceful firms are often easier to engage, while SMEs and third sector actors require more targeted marketing. Using marketing and building networks to find the right innovator for the testbed can uncover new firms and emerging talent in the industry.

Especially when real-world testbeds are long-term stable environments open to innovators, they require a plan for marketing. This would allow facilitators to reach out to suitable innovators, highlighting the opportunity it represents. Most real-world testbeds involve large, well-resourced firms because of their market share, economies of scale or networks, but they might not always have the best new ideas for testing.

SMEs, third sector organisations, international or non-local actors can miss out on such opportunities, either through lack of information or resources. In many cases, disseminating the opportunity to these and other relevant innovators is crucial to ensure the real-world testbed is inclusive and that the state-of-the-art technologies are represented. A mix of larger and smaller innovators could also lead to knowledge spillovers and improved local economic impacts (should the innovators be local).

Key resources

Resources for marketing are widespread and difficult to generalise for real-world testbeds specifically. In terms of including SMEs, which many real-world testbeds share, the table below illustrates some frequent challenges based on the shared difficulty of including SMEs, and potential solutions.[26]

Challenge for SMEs	Potential solutions
The testbed is too costly for participation.	Subsidising the participation of SMEs either directly or through challenge funding earmarked for a certain type of innovator. Providing SMEs with free access to the real-world testbed.
Lack of knowledge about real-world testbed opportunities for relevant SMEs, or doubt in the worthiness of the testbed participation.	Having part of the real-world testbed budget earmarked for marketing purposes. Creating support structures for SMEs that increase their potential benefits and outputs.
SMEs not the primary target group.	As many real-world testbeds may prefer to work with large companies, those that involve SMEs, or plan to do so, can be rewarded or gain preference in funding applications. Smaller innovators can be involved through working methods such as workshops or labs concerning the real-world testbed topic.
Fear of exposing their products/ processes.	Having clear frameworks on Intellectual Property (IP) implications and building trust and transparency within the testbed.

5.7 Working with regulators

In many cases, especially with disruptive technologies, regulation may be less developed or in some cases not exist whatsoever. Real-world testbeds could be a valuable tool for both regulators and innovators to build a dialogue, and for regulators to build the necessary knowledge to regulate and get answers to their questions regarding the innovation. Early involvement of regulators allows them to co-design the real-world testbed, build a trusting relationship and find structured ways of working.

Regulation is a key element of the introduction of innovation into the real world. Regulators should be brought along at every stage of the process and should be a collaborator rather than an organisation causing barriers to innovation. At the beginning of a project, a stakeholder analysis should be conducted that will identify regulators in the field.

Recommendations

- Be clear about what is being tested and the relevant laws, regulations and policies which may be affected, then clarify whether the testbed will need authorisation or involvement from more than one regulator.
- The earlier the involvement of the regulator, the better. This provides the opportunity to better understand the regulatory frameworks and include this into the design. Regulators may be able to help to create a 'safe space' for testing technologies and get to test methods of regulation themselves.
- It may be possible, or even necessary, to involve the regulators in the design and governance of the testbed. This should be regarded as an opportunity, not a barrier.
- Learn from other regulatory testbeds operating in similar sectors and environments; there are potentially opportunities to share lessons learned and avoid making similar mistakes.
- Policy labs can be a good approach to integrating regulation and other required competencies within a testbed, or across several testbeds. A policy lab can be a temporary initiative or a more long-term and permanent investment. This is a format that has the potential to work well with testbeds, as it provides an additional feature of seeing the regulation 'in action'. In Gothenburg, policy labs have been introduced as a means of tackling some of the more complex issues around innovation, such as autonomous vehicles and their integration into society.

5.8 The transition from testing to commercialisation

Once the technology has been proven safe, effective and ready for demonstration, there are some key considerations in the transition to demonstration and commercialisation. One key differentiator is that in the testbed it is acceptable to fail, while in the demonstrator failure is not accepted. A testbed is a place for testing, evaluation, learning and re-testing. Demonstration is a phase in which the innovation – as proven safe – can be shown to stakeholders, including regulators and the general public, to build acceptance and support. A plan for disseminating evidence to the market and building business cases and financial cases for market exposure should be developed alongside the testbed.

Planning for demonstration and commercialisation phases should begin in the testbed. The learnings, improvements and relationships developed in the testbed should be built upon to deliver demonstration and attract further investment for scale-up. The early business case developed at the start of the testbed should be built out with the evidence from the testing, to build the case for further investment in the development and roll out of the technology. Using evaluations in the testbed in this phase can inform the economic and financial cases, and any process evaluation should inform the management case for future implementation.

6 Conclusions and policy lessons

This report has dealt with the question of what real-world testbeds are, why they are useful, and how they can best be utilised. The findings and framework of this report is based on desk-based research, a bank of eighty examples from across the world, case studies and interviews with testbed actors, and expert insights.

This research defines real-world testbeds as:

> "Controlled or bounded environments for testing innovations in real-world or close to real-world conditions in the manner (or close to the manner) in which they will be used or operated."

Amongst other qualities, they can reduce the barriers to testing by helping manage risk, change and test regulation, allow access to real-world environments and user groups or their associated data, which is often a necessity for innovators before commercialisation. Real-world testbeds are particularly suited for technologies operating in complex systems, requiring evidence and interactions with the real world to prove their safety and usefulness. The format of testbeds allows the management of risk, experimentation, learning, evaluation and de-risked failure.

There are examples of established and new real-world testbeds across most sectors. They include innovators, local and national governments, public sector bodies, research, charities and other institutions. With technology moving at such fast pace, it is crucial for policymakers to facilitate testing trailblazing innovation in the real world, to learn about their effects. It is also vital for innovators to gain access to testing their products, processes and services in the environments they are intended to be used in.

Public sector involvement in this kind of innovation infrastructure is important to incentivise the sector to innovate in a safe and controlled manner. Using environments such as hospitals, roads, schools, land, university campuses or neighbourhoods as testbeds also makes more use of such infrastructure, adding to their value to society.

Real-world testbeds can be used for many different purposes and objectives, depending on the stakeholder and context of the testing. At the core of every testbed is the need to test new innovation, often new technologies, for verification and proof of concept. They can also be used in a place-focused manner, serving as a tool to solve local challenges, market a place to businesses and talent, and contribute to local economic development. They can be used to respond to market failures and grand challenges or facilitate gaining competitive advantages in frontier technologies. Real-world testbeds can also be used to cut costs and improve public services, testing which technologies serve this objective better. Finally, this report has covered the use case of exploiting real-world testbeds to adapt regulatory frameworks.

Lessons for future testbeds

Testbeds should be considered as a tool to incentivise innovation and the spread of good solutions

With all their potential benefits, testbeds should be considered as a tool used in innovation policy across sectors and geographical levels of authority. If designed and operated in the right manner, they can facilitate much-needed collaboration and coordination of private and public stakeholders with aligned objectives. They can de-risk the process of procuring innovative solutions to complex problems for the public sector and incentivise socially beneficial use cases of innovation.

Testbeds should not be stand-alone policies, but part of a more extensive strategic approach

Real-world testbeds will have a greater impact if co-ordinated with other innovation policies in parallel. Real-world testbeds and other test and demonstration facilities such as labs and simulated environments should be part of a broader innovation infrastructure, enabling learning from one another's approaches. Other innovation policies along the innovation process, such as supporting idea generation and development, are still vital and should be part of a strong and integrated innovation system on a national and local basis.

A coordinated testing and demonstration infrastructure could deliver additional benefits

As various types of testbeds and demonstrators are established across the world, innovation agencies should gain an overview of these programmes in order to coordinate, market and share learning across the various initiatives. This is carried out successfully in Sweden through a national strategy for testbeds – a process that other countries should seek to learn from.

Regulators should be involved early and actively

Real-world testbeds represent a unique opportunity to test regulatory approaches for trailblazing technologies. If regulatory bodies are involved at an early stage and throughout the process, there is a higher probability that proper and safe regulation can happen.

Relevant governmental and/or innovation agencies should seek to agree on a shared terminology for innovation policy tools

To ensure a shared understanding of the many terms and tools within innovation policy, relevant government bodies and institutions should agree on shared terminologies. This is important to avoid confusion and create clarity and standards for testers, regulators and investors.

Ethical considerations should always be front and centre

Many testbeds deal with complex ethical situations, including use of citizen data and introduction of health technology. These considerations should always be front and centre when testing innovation, and the time spent to deal with them should not be underestimated.

Appendices

Appendix 1: Bank of examples

Name	Geography
The Canary Islands Oceanic Platform	Canary Islands (Spain)
Autonomous shipping testbed	Norway
I-STREET	USA
NHS Testbeds programme	England
Singapore AV initiative	Singapore
Maritime Autonomy Surface Testbed	UK
Smart Kalasatama	Finland
Living Lab Bus	Finland
TRL UK Smart Mobility Living Lab	UK
Growth Corridor	Finland
UK Autodrive	UK
Smart Santander	EU/Spain
EnergyBlock	Denmark
Copenhagen Street Lab	Denmark
ROBOAT	US/Netherlands/UK
LaMiLo – Last Mile Logistics	EU
Digital Motorway Testbed	Germany
US Autonomous Vehicles Proving Ground	US
Urban Drone Testbed	Sweden
Jurong Lake District	Singapore
FinTech Regulatory Sandbox	Singapore
Number 9 – Unmanned and manned aircraft testing	Finland
Sohoja and Nordic Way Projects	Finland
ICT testbeds project	UK
Pervasive Nations	Ireland
Smartbay – Test, validate, innovate	Ireland
Concept House Village	Netherlands

Hållbarheten – Smart Homes	Sweden
IoT Lab	France
DRIVEME	Sweden
ElectriCITY	Sweden
LA Cyber Lab	USA
FED – Fossil Free Energy Districts	Sweden
Chalmers Five Star Campus	Sweden
Innovation Platform VGR	Sweden
Test site Akvamarin	Sweden
PICTA – Perhospital arena, mobile testbed	Sweden
Testfield Niedrichstrassen	Germany
Project Wing	Australia
GATEway project	UK
Midlands Future Mobility	UK
Nordic Testbed Consortium	Nordics
Sunnaas Testbed Facilities	Norway
Centre for Welfare Technology	Denmark
Centre for regional development, research and innovation unit	Denmark
The health and care administration testbed	Denmark
Intervention Centre, Oslo University Hospital	Norway
Operating room of the future	US
Sheridan Elder Research Centre	Canada
Save the peaches	Argentina
Queen Elizabeth Olympic Park	UK
Mistel	Sweden
Drone Centre Sweden	Sweden
UK 5G testbed	UK
The Sharing Cities Programme	EU
Riksbyggen Positive Footprint Housing	Sweden
Elmob – electric vehicles for sustainable travel	Sweden

iDag – innovative test environment for distance learning	Sweden
Carbon Credits from the woods	Sweden
SICS ICE	Sweden
High Voltage Valley	Sweden
Experio Lab	Sweden
Karolinska – Testbed for telemedicine	Sweden
The national testbed for innovative radiotherapy	Sweden
KTH Live-In-lab	Sweden
iZone	USA
MindCET	Israel
Digital Promise	USA
European Schoolnet	Europe
EDUlabs	Estonia
Qinzhou Intelligent Urban Water Supply cloud service testbed	China
Manufacturing quality management testbed	China
HarborNet – A real-world testbed for Vehicular networks	Portugal
World Cup Russia – Testbed for Sports Technology	Russia
5G testbed, Department of Telecommunication	India
Cross-border regulatory testbed for AVs	France/France/Germany/ Luxembourg
Digital Greenwich	UK
FCA regulatory sandbox	UK
Krafla Magma Testbed	Iceland
5G RuralFirst	Orkney
Marriott Hotel Testbed	Middle East and Africa

Appendix 2: Full case studies

2.1 Milton Keynes as a testbed – key facts

Description

Milton Keynes is the largest 'New Town' in England. Founded in 1967, the city was originally conceived as a commuter hub, situated roughly equidistant between London and Birmingham and Oxford and Cambridge. It is currently one of England's most economically vibrant towns, with one of England's most productive workforces, generating more start-ups than any city outside of London.

Milton Keynes has a rich tradition of testing technology in the urban environment. The first testbed in Milton Keynes was the 'MK: Smart', a project to develop capability for management and use of big data. This was a £16 million collaboration between academia,[27] industry[28] and MK Council. The collaboration created a data hub based at the Open University, focussing on energy, transport and water monitoring and data collection. The city has subsequently collaborated with testbeds on electric bus schemes, rapid electric vehicle charging, CAVs, delivery robots and sensor technology.

Purpose: Solving local urban challenges through testing new technology, building on the 'brand' of being a New Town through being innovative and testing the validity of new technologies.

What is being tested

- **Electric bus fleet**: A testbed aimed at delivering a clean and commercially viable electric bus fleet.
- **UK Autodrive**: A three-year, consortium-based project facilitated by a government-backed competition to support the introduction of self-driving vehicles into the UK.
- **MK:Smart** – MK data hub supporting acquisition and management of big data relevant to city systems in the areas of energy, water and transport management; A smart city education programme providing training in advanced technology; Engaging citizens through a citizen lab.
- **Starship delivery robots**: Starship, a company using robots to deliver food and products.

Core lesson – using testbeds for marketing, local challenges and economic development purposes

Milton Keynes has operated as a real-world-testbed for a number of years, providing areas within the city for projects and companies seeking to test their technologies and solutions. This is claimed to be important both to creatively solve urban challenges and reinvent itself for the 21st century. In their Economic Development Strategy, Milton Keynes City Council states that MK is at the forefront of new and innovative technologies, and that the status as a forward-thinking, smart city should be used to further brand the city and enhance the sense of place.

> "It gives the city a competitive edge, as a location of choice for business development both nationally and internationally, and as a city where people want to live, work and visit."
>
> **Milton Keynes Economic Development Strategy 2017-2027**

The council has several designated roles working with testbeds, including Head of Transport Innovation and a Director of Strategies and Futures.

- **Using real city challenges to design the real-world testbeds**: One key principle on which the MK Council base their testbed activity is whether the technology tested can contribute to solving local challenges. Many of the MK testbeds have been focussed on transport as the city is planned to double in size by 2050. With this ambition comes a requirement to adapt the transport system for more passengers, whilst avoiding worsening air quality, an increase in carbon emissions, and expensive investments in infrastructure.

  In several cases, MK has also designed the challenge for which the technology can be tested to solve. For example, in the UK Autodrive project, the challenge was set to create a more liveable city centre less dominated by cars, and solve some of the safety issues such as their problems with sideway collisions: a real problem causing the council a lot of anxiety.

- **Using testbeds as a response to budget constraints**: Using testbeds to trial technology also contributes to solving urban challenges in a world of public sector budget constraints. Procuring unproven technologies to solve challenges can be both risky and expensive. The MK approach has been to facilitate companies' opportunity to test their products and develop their business case. The reward from this is that the technology is verified and can be implemented into other markets more rapidly, which is a better alternative to funding such a solution, which the council on their current budget would struggle to do on a similar scale. The testbeds also provide a stronger case for whether this is 'the right tech-horse to gamble on'.

- **Attracting investment and activity**: The testbed activity and overall brand of Milton Keynes has led to companies 'lining up' to test their technology in the city. This has often come as a result of participation in large projects, such as UK Autodrive. The projects are prioritised based on which problems they can solve for the city, or which represent other clear benefits. Not all projects materialise, but it provides opportunities for inward investment and activity, an aim in the city strategy.

- **Playing to the local strengths**: In addition to responding to local challenges, Milton Keynes has also played to local economic and locational strengths. The robot delivery and autonomous pods testing has been easier to carry out in the city as it is designed more recently than many other cities with, for example, wider footpaths. Another example is the idea of facilitating drone testing in the area, as the city is located in close proximity to an Amazon distribution centre.

Other lessons learned

Using the testbed to verify the technology

- Testbeds can be useful not only to solve urban challenges and promote economic development, but also as a useful validation method to see whether the technology is all that it claims in the sales brochure. Testing technologies in the local context will contribute to fewer unviable investments, and also verify whether the technology in question functions in the local environment with a true demand from citizens.

Regulatory challenges

Testbeds can also contribute to solving regulatory challenges associated with new technologies, for example in cases where the technological development has moved beyond the appropriateness of current regulation.

- The Milton Keynes Transport Plan further states one of the desired outcomes as 'a modern regulatory system that works to improve the way transport regulation supports improvements in the transport system'. Testbeds can provide an opportunity to test and adapt current regulations, developing the framework alongside the tests and avoiding being 'on the back foot' once the technology is ready to be deployed.
- Milton Keynes has also contributed to regulatory discussions with the Department of Transport, together with some of the companies testing technology in the city. An example is the testing of electric cycles with Lyme and electric scooter companies, which are currently prohibited on footpaths in the UK. The experiences from testing these services in MK could better inform a potential adaptation of such regulation.

Incorporating learning and allowing flexibility

Testbeds can, if designed accordingly, be a great way of learning how to improve urban design and development.

> "There are outcomes that could never have been anticipated, new questions that come up along the way, and we learn from that as much as the technology developer. It gives us insight on how to develop our city for the future of transport."
>
> **– Brian Matthews, Head of Transport Innovation at Milton Keynes Council**

- Several outcomes from testing technologies can provide valuable learning that could not have been obtained outside of a real-world environment. One example is the testing of the Starship Delivery Robots. The expectation and scepticism prior to the project concerned whether it would make people lazier, stopping them cycling to shop for groceries. Instead, the scheme removed about 1000 cars off the road, as the project illustrated that trips to the grocery shop were carried out by car, an unexpected outcome and a positive surprise.

- The evolution of testing means that the right questions will not always be obvious at the beginning of the testbed period. It is important to stay flexible to develop the testing as the questions and assumptions change.
- Another unexpected outcome from the Starship Robot testing came from a citizen in Milton Keynes:

> "We received a letter from a mother who had a child that refused to eat fruit and vegetables…Until the day it was delivered by a robot."

Involving citizens

Involving citizens is a core priority in Milton Keynes' testbeds, as they are the primary users and beneficiaries of the technology being tested.

- Testing new technologies with citizens depends on dissemination. If the testbed is carried out for the right reasons, it is much easier to get the citizens on board. When MK Council tests autonomous vehicles to respond to the need for a better transport system, the citizens are more willing to accept the testing.
- Most of the technologies tested in Milton Keynes have had a positive reception from the public. There can often be initial concerns which relate to 'fear of the unknown', however this largely disappeared with a planned and managed way of introducing the technology.

Collaboration with the private sector

- Aligning objectives can take time when there are many participants in a partnership, however frequent meetings with the same representatives and an open approach tends to build the necessary trust. With UK Autodrive in Milton Keynes, it took ten months to establish the collaboration agreement across 16 partners.
- It is also important to listen to private sector partners to create as much of a win-win situation as possible. Jaguar Land Rover was part of the UK Autodrive partnership, and it took flexibility on both sides to achieve a shared objective. Milton Keynes originally wanted them to provide services to more deprived areas with their shared car service, however this was too far away from Jaguar's market, which is more focused on high-end. The council ended up agreeing to the objective of reducing the number of cars on the road and looking for a different partner to achieve their original objective.

Concerns about data

A concern raised in Milton Keynes is the need for continued research and insights into data management and privacy issues.

- Schemes that focus on data issues should be carried out alongside local testbeds to improve the general environment and to stay on top of the development.

Impact

- Milton Keynes is recognised, largely due to the testing activity in the city, as one of Britain's top 'smart cities'.[29]
- The main impact from the high-profile testing activity in Milton Keynes is the brand obtained by the city as the 'place to go' for testing innovative solutions. This can be seen through national and international media narratives.[30, 31]
- The testing activity brings several companies with innovative transport solutions to Milton Keynes and the city council. The city has managed to accept the testing of only those solutions that are suitable to the local challenges of the city, thereby increasing the likelihood of benefits for the city.[32]

References

Interviews with

Brian Matthews, Head of Transport Innovation, Milton Keynes Council

Other literature

Milton Keynes Futures 2050 Commission. *Making a Great City Greater*. https://drive.google.com/file/d/1Zi-hD-RVwS_9Gz50C5m6hNhHTpcEtheN/view

Milton Keynes Council (2017) *Economic Development Strategy 2017-2027* https://www.milton-keynes.gov.uk/assets/attach/46815/FINAL%20Economic%20Development%20Strategy%202017-2027.pdf

Milton Keynes Council (2018) *Mobility Strategy for Milton Keynes 2018-2036 – Mobility for all*. https://www.milton-keynes.gov.uk/assets/attach/51006/2018-03-21%20Mobility%20Strategy%202018-2036%20(LTP4)%20ADOPTEd%20by%20Council%2021%20March%20FINAL%20submitted%20copy.pdf

Simpson, Paul (2018) *Smart cities special: Why Milton Keynes is more than just roundabouts*. https://www.cips.org/en-GB/supply-management/analysis/2018/september/smart-cities-special-more-than-just-roundabouts

UK Autodrive (2018) About: http://www.ukautodrive.com/the-uk-autodrive-project

2.2 NHS testbeds – key facts

Facilitator

A cross-government venture funded by NHS England, the Department of Health and Social Care and the Office of Life Sciences (OLS).

Purpose: Make public services better and more cost-efficient; Spreading useful innovation throughout the NHS; Changing the NHS innovation culture.

What is being tested

Wave 1 tested three different types of innovation:

1. Predictive algorithms to manage patients at risk of developing a condition.
2. Aggregation of data into one place to inform operational and clinical decision making and improve an individual's ability to manage their condition.
3. Technology to monitor risk of crisis in clinical pathways or an individual home or care home.

The testbeds in Wave 1 were:

- **Lancashire and Cumbria Innovation Alliance** – Improving support for those over 55 with Chronic Obstructive Pulmonary Disease, heart failure and dementia. Integrating technologies and linking them to new care models supporting self care at home. **Participants**: 1,600 **Innovators**: 8
- **Long-term conditions early intervention programme** – Promoting early intervention to reduce the burden of ill health by developing a predictive algorithm, redesigning pathways and training health professionals. **Participants**: 214,700 **Innovators**: 2
- **Diabetes digital coach** – Providing people with type one and type two diabetes with a selection of integrated IoT digital tools to manage their condition. **Participants**: 1,000 Innovators: 8
- **Perfect patient pathway** – Improving pathways for asthma, diabetes, falls and frailty by increasing access to technology and facilitating information sharing. **Participants**: 1,300 **Innovators**: 7
- **RAIDplus** – Developing a demand and capacity tool that shows patient flow in real time and a predictive algorithm to identify when people are going to experience a mental health crisis. **Participants**: 33,000 **Innovators**: 2
- **Care City** – Testing a combination of digital devices and software alongside new approaches to service delivery and patient participation. **Participants**: 4,100 **Innovators**: 6
- **Technology integrated health management** – Providing people with dementia and their carers with: wearables, monitors and other devices which will combine into an IoT to monitor their health at home. **Participants**: 1,400 **Innovators**: 7

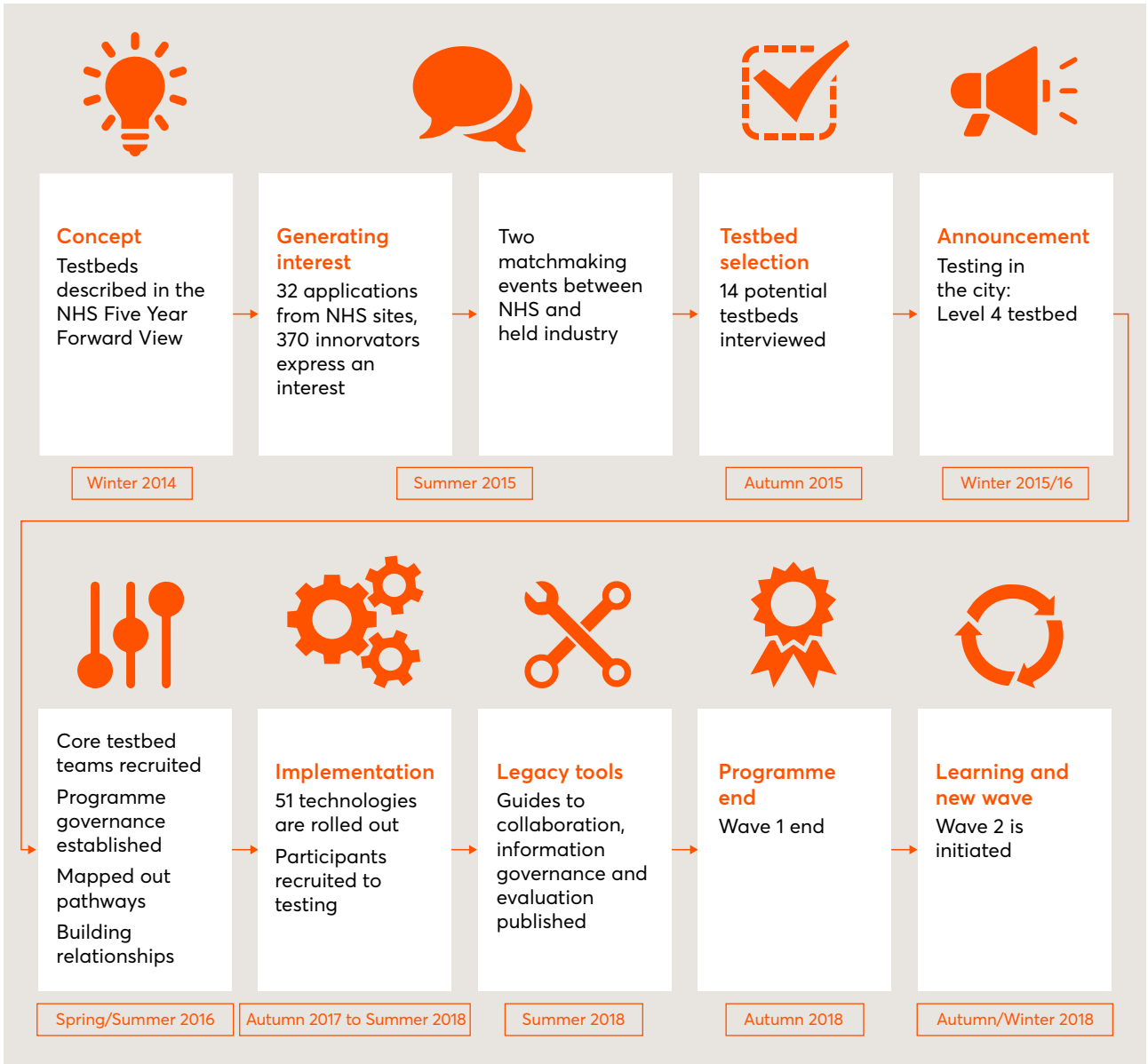
Organisation

Each testbed brought together partners from senior government, academia, industry, patient groups and charities. Organised in Waves, the second wave commenced in 2018 and will run to 2020.

Budget

£9.5 million from NHS England, the Office for Life Sciences (OLS) and Department of Health. £15 million was leveraged from industry.

Figure 6: Timeline and programme of Wave 1



Core lesson – evaluation

Evaluation was described as fundamental to the testbed programme. The aim was to provide robust evidence of what worked well and areas of improvement across the following four questions:

1. Did the intervention improve patient outcomes?
2. Did the intervention lower health system costs?
3. What changes were made to the intervention or implementation and why?
4. Have NHS-innovator partnerships worked and why?

The NHS testbeds programme was designed in waves. The first wave consisted of seven testbeds over a period of two years. Each of the testbeds were required to have an evaluation plan, including qualified personnel to carry it out. Many chose to collaborate with a local university to get an unbiased evaluation. The structure of waves also allowed for a structured implementation of the learning obtained from the first wave into the second. In terms of evaluation, a handbook was published with detailed description of methods and learnings, designed for future testbed designers and operators.

Figure 6 illustrates the steps taken throughout the evaluation process of the first wave. There are a number of transferable lessons from this approach.

The NHS approach to evaluation

Step 1 – Be clear on the scope of evaluation

- Define the intervention to be evaluated, technology to be used and services to be changed.
- Articulate the intervention and what would have happened otherwise.
- Articulate the context in which it is being implemented and the technological maturity.
- Define what is out of scope.
- Agree percentage of budget to be used on evaluation.

Step 2 – Agree what you want to learn from the evaluation

- Decide what kind of evaluation is required (process/impact/economic).
- Work with key stakeholders to articulate questions to facilitate the evaluation.
- Develop and implement learning and dissemination plans.

Step 3 – Identify who needs to be involved

- Consider who needs to use the evaluation findings.
- Identify who should input to ensure a comprehensive and robust evaluation.
- Facilitate input from funders, patients, clinicians, delivery teams, data security teams etc. Ensure alignment with governance of the wider intervention.

Step 4 – Set up an appropriate governance process for project close down

- Follow best-practice guidance and form an advisory group with external experts, with clear reporting lines.
- Ensure appropriate involvement form patients and the public.

Step 5 – Get the right evaluation team

- If commissioning an external evaluation team, ensure an open and fair process.
- Ensure the team has the required skills and experience in evaluation.

Step 6 – Agree ways of working with evaluation team

- Facilitate clear communication channels between the evaluation and implementation teams.
- Set up appropriate information governance processes.
- Agree regular engagement between the teams.

Step 7 – Ensure joint ownership of evaluation approaches

- Ensure a logic model framework for the evaluation is prepared.
- Ensure the most robust methods are selected, given data and practical constraints.
- Ensure methods are appropriate, given the maturity and context of the interventions.
- Ensure methods can be integrated to maximise learning.

Step 8 – Be an intelligent customer for the evaluation

- Play a scrutiny role. Ask questions of the team to ensure you fully understand the activities.
- Monitor patient recruitment activity and be prepared to suggest adapting to maximise numbers.
- Test and challenge findings to ensure appropriate interpretation.

Step 9 – Ensure preparation of a clear evaluation protocol

- Agree accountable representatives across evaluators and implementors with the relevant ethics clearance.

Step 10 – Ensure findings and context are clear in final reporting

- Ensure context for the interventions is clearly conveyed (the system in which the interventions were implemented).
- Ensure findings identify conditions under which outcomes were observed, for whom and why.
- Sense-check results and findings, including limitations and unintended consequence.

Step 11 – Take stock of learning and embed it in future action

- Identify key points of learning from the evaluation.
- Identify practical ways to put this into action for future interventions.
- Translate evaluation findings for policy makers to use.
- Set up framework to continue to monitor ongoing interventions.
- Make appropriate learning experiences available to relevant stakeholders.

Step 12 – Ensure dissemination plan is put into practice

- Continue appropriate sharing of learning throughout evaluation.
- Ensure dissemination materials are prepared with clear messages.
- Ensure frontline staff, public and patients are among those with whom learning is shared.

Other lessons learned

Further lessons learned were obtained from a series of interviews with key stakeholders involved in the first wave of testbeds.

Finding and working with the right partners and collaborators

The NHS testbeds programme had several stakeholders involved in different ways of working. The seven testbeds in Wave 1 were established based on the technology tested and the patient groups they were working with. Some were naturally more comprehensive than others. However, some overarching lessons were valid across all:

- Do not underestimate the time required to develop mutually beneficial partnerships, recruit patients and operationalise the innovation. Getting the testbeds set up took longer than anticipated, both from the public and private sector point of view. These were areas that the first wave identified as particularly sensitive to time management:
  - Getting the core team in place
  - Determining terms of collaboration and work
  - Testing phase
  - Evaluation
  - Information Governance and decision-making

- The NHS programme involved several stakeholders from national and local levels of the NHS and government, large and small private companies, academia and the voluntary sector. The more partners were involved, the harder it became to align competing objectives. For example, one testbed had 19 partners, leading to difficulties in the decision-making process. One of the interviewees claimed that it would have been much easier to disappoint a further ten partners, than to work with such a high number of partners. Smaller partnerships with fewer stakeholders within the group were more successful.

Clarity of purpose and simplicity of tasks

- With the private sector, national and local public sector representatives involved, there will be a series of competing objectives. The companies aimed to partner with the NHS, access patient data and verify their products. Some wanted to use the testbeds to allow SMEs access to innovate in the NHS, while others wished to use them to make local NHS bodies, with little tradition for R&D work, 'catch up'. It was vital to clarify which aim was most important and stick to this aim. Although this was very difficult, the core aim of establishing cost-efficient methods of delivering quality care was set as the primary goal.
- Clarifying what technologies will be tested is also key to success. It can be tempting to test a range of different products, however those that had a more straightforward design with fewer technologies were also the most successful.
- Asking the industry the right questions about how their products fit into existing pathways is critical for the long-term success of the technology implementation.

The importance of qualified leadership, local ownership and hand-holding

- All of our interviewees mentioned the importance of collaborating with local NHS bodies that were actively engaged and interested in implementing digital technologies. Without this, they claimed the programme would struggle to function. Some also emphasised the importance of senior involvement, in both national and local bodies, to ensure this.
- One of the significant factors that determined the applications of the local NHS bodies was the evidence of strong leadership with proven experience in similar projects. Testbeds that were chosen despite this were also those that struggled most in the process.
- A lot of 'hand-holding' was required from the facilitators throughout the process. Each testbed had a Senior Responsible Officer (SRO) who held monthly and quarterly meetings with the testbed. This was key to identify and deal with challenges along the way and ensure progress.

Funding

- If possible, try to obtain a longer-term funding stream that ensures the stability of the programme in a political landscape with much insecurity.
- The NHS testbed programme funded several operations on behalf of companies. There is a need to be strict to provide funding to those who need it the most. Does the testbed need to fund large companies with stable incomes, or should the funding for the private sector instead be used to provide access to SMEs?
- Some testbeds are not too expensive to run. These are often simple with more mature technologies.

Information governance and risk management

With a complex system of technologies, data, different stakeholders and geographic locations, a robust information governance framework was essential to the NHS testbeds programme.

- The information governance process also included identifying and managing risks related to Data Protection. It was key to create an overarching log of all possible risks and to review and log new risks as the programme went along. The NHS testbeds programme recommends monthly risk review meetings.

- Early and transparent communication of the testbed's approach to using patient data, including benefits and outcomes, is key.
- Future testbeds should not overlook or underestimate the GDPR[33] implications to some testbed objectives.

Impact

- The clearest evidence of success from Wave 1 was the substantial, continued investment of Wave 2 by the funding partnership.
- Programme leaders claimed that, whilst not everything was effective, there had also been huge successes. This has particularly been seen in the use of IoT devices monitoring patients with complex conditions such as dementia and diabetes. The devices tested showed a decrease in the number of necessary visits to health service providers, and a better way for health professionals to monitor the condition.[34]
- The number of participants in the testbed programme, and the data generated from the use of new technologies, allowed NHS health professionals to develop their services more accurately.[35]
- The testbed in Lancashire and Cumbria saw impacts of a 2.7 per cent decrease in probability of being admitted to hospitals, a 10 per cent reduction in primary care community and emergency services, as well as an 86 per cent increase in patient confidence on their own health, and a 68 per cent increase in indicated knowledge and skills enabling self-management of long-term conditions.[36]
- Data from Phase 1 indicated that during the testbed programme, there were improvements in experience of healthcare, resulting in a reduction of emergency care and hospital admissions in the long term.

References

Interviews with

Will Cavendish, Previously Senior Responsible Officer (SRO) of the NHS Testbeds Programme, Department of Health.

Nicole Mather, Previously Head of Strategy in the Offices for Life Sciences (OLS) and SRO of testbeds.

Michael MacDonnell, Previous Head of the Testbeds Programme for NHS England.

Literature

NHS England Test Beds Programme: Evaluation Learning from Wave 1 (2018). https://www.england.nhs.uk/wp-content/uploads/2018/11/test-beds-programme-evaluation-learning-from-wave-1.pdf

Test beds – *The Story So Far (2018) NHS England*. https://www.england.nhs.uk/wp-content/uploads/2017/09/test-beds-the-story-so-far.pdf

NHS England Test Bed Programme – *Information Governance – Learning from Wave 1* (2018) https://www.england.nhs.uk/wp-content/uploads/2018/09/test-beds-programme-information-governance-learning-from-wave-1.pdf

2.3 Smart Santander[37] – key facts

Description

Smart Santander was an IoT testbed funded by the EU which included the cities of Santander (Spain), Lubeck (Germany), Belgrade and Guilford (UK). At the time, the most extensive urban infrastructure in the world was deployed: over 20,000 sensors across these cities communicating with the deployed IoT architecture. The testbed is regarded as a success and Santander, in particular, is now recognised as a trailblazer of Smart City technology deployment. Since the official testbed ended, many of the tested technologies were implemented into the city and are still developed and used.

Figure 6: Sensor deployment in Santander

What was tested

Overall, what was tested were the approaches to, and building blocks of, the IoT architecture; evaluation of the IoT interaction with device technologies; and critical services such as discovery, data management and services. Santander was the city testing most citizen services through over 12,000 sensors, amongst others:

- **Environmental monitoring** of temperature, Co_2, noise, light and car presence.
- **Remote dimming of street lamps**: Street lamps are dimmed while streets are empty or when other light sources, such as the full moon, are present.
- **Efficient garbage collection**: The garbage collection system is made more efficient through sensors identifying which bins are not full – reducing needless trips.
- **Outdoor parking area management**: 400 parking sensors buried under the asphalt manage and communicate availability.
- **Parks and garden irrigation**: Making irrigation as efficient as possible through measuring moisture, humidity, the temperature in relevant parks and gardens.
- **Augmented reality features on tourist attractions**: Providing useful information about several buildings and attractions in the city.

The sensors and their uses were installed in phases between 2010 and 2013. Each stage contained different types of sensors depending on the final services. Some were static, buried in the asphalt or placed within street lamps or boxes, others were mobile, situated on the city's public transport network, including buses, taxis and police cars. By downloading an app to their smartphones, citizens could also become moving sensors in their own right.

Main actors involved: The Smart Santander project was funded mainly by the European Union's Future Internet Research and Experimentation (FIRE), which consists of the creation of facilities to support experimentally driven research in the field of Information and Communication Technologies (ICT). The €6 million grant funded the consortium of 25 partners from across Europe and Australia. The cities involved were Santander (Spain), Belgrade (Serbia), Lubeck (Germany), and Guilford (UK).

Purpose

The purpose stated by the Smart Santander project was dual: 1) to facilitate real-world experimentation of IoT technology to achieve a leading role for European cities in IoT technologies, 2) to provide useful services tailored to the cities during the testbed operation.

Core lesson – capturing competitive advantages in a frontier technology

Santander is a city of around 180,000 people, most known as a city of tourism. Through the Smart Santander programme, it has been transformed into one of the most recognised smart cities in the world. The EU-funded testbed has, according to participants, diversified the economy of Santander and placed European cities at the forefront of using IoT technology in urban planning and development.

It has also achieved the aims set by the EU, one of which was to 'achieve a leading role in Europe in the IoT technologies'. In their evaluation report, the European Commission stated that "The project has successfully achieved all its objectives, even exceeding initial expectation." The following elements were key to this success:

- The testbed as a tool was highly beneficial for the involved partners. Professor Luiz Muñoz, the lead coordinator of the partners, stated **that the testbed format was a much more practical approach for the researchers**, allowing them to learn, but also be expected to produce results.
- The testbed format in the real-world environment served as an **excellent catalyst and necessary critical mass for IoT research**. It also facilitated collaboration between research institutes, citizens and private sector actors to operate their tests and develop their products. The testbed created a framework for collaboration that led to the more rapid development of IoT technology.
- **Using a testbed that involved citizens in facilitating the testing boosted credibility and made adaptation easier**. Some of the sensors already installed in the city stayed there after the testbed period was finalised, simply changing its status from 'testing' to 'operating' within the real world.
- Testbeds that are built around accurate and locally specific urban challenges, not merely 'to test a sensor', also increases the opportunity of a positive testbed legacy.
- To achieve the competitive advantages on a supra-regional scale such as that envisioned by the EU, the testbed area requires adequate scale, length of time to allow learning and improving, well-run partnerships with win-win outcomes, and sufficient funding.

- The EU FIRE project is a large funding programme that spreads funding across several aspects of the future of the internet, such as AI, cloud services and other wireless technology. This spreads the risk of investing in 'future trends' and facilitates learning between the projects.

Other lessons learned

Involving citizens early

There is no smart city testbed without citizen involvement. If you put technology into the city that people cannot use, or do not like or accept it, then the city risks not being 'smart', only technology-led. A testbed is an excellent way of testing services and sensor presence with citizens at an early stage.

- Santander used the data coming in every two minutes from the 12,000 sensors, to create a '**Pulse of the city app**'. The app makes the data accessible to the citizens and puts them at the heart of public service delivery. Through the app citizens could, for example, point their device towards any bus stop to obtain information about when the next bus will arrive. They could also use the app to report everyday annoyances such as potholes or other damages to the public realm, forwarded to the relevant authority.

Involving SMEs

It was important to the EU and the cities involved to allow SMEs to be involved in the infrastructure. The solution from Smart Santander was to incentivise their involvement without expecting financial contributions. This was done through, for example:

- Workshops with SMEs on city challenges and IoT responses.
- Providing challenge-led funding that SMEs could apply to, with bespoke solutions.
- Facilitate close collaboration with the SMEs, the research institutes and large companies involved to facilitate the increased capacity of contribution.

Local economic development and inward investment

The close coordination of the city council and the local economic development agency in Santander was vital to harness the local competitive advantages. According to Luiz Muñoz, the city has now diversified its economy through attracting companies and researchers wanting to learn from the Santander approach, use the open data available, or offer services attached to the IoT Architecture. Some elements stood out as being particularly important in harnessing economic development benefits for Santander:

- The involvement of the economic development agency in Santander from an early stage allowed for a long-term marketing plan, and participation of local economic actors throughout the process.
- The success of the programme created a new source of marketing for the city. From being a tourist destination, the city is now known for being one of the pioneers of smart city development. The city council, researchers and companies involved are often invited to share their model and experiences with cities worldwide. Although the success of Santander generated a lot of free marketing, this can be achieved by others through a conscious marketing strategy by relevant stakeholders.

Impact

- The most important results of the real-world testbed activity include improvement in the quality of citizens' lives, optimization and reduced costs of the urban services provided, as well as positioning the city as a world leader in the field of innovation.[38]
- A report by McKinsey[39] lists Santander among the ten strongest cities in Europe regarding its smart city technology base,[40] higher than Berlin, Paris, and Moscow.
- It also finds that citizens were both aware of the available technology and highly satisfied with it.
- Santander is considered a pioneer smart city due to its widespread deployment of mobile and fixed IoT devices, which has come as a direct result of the real-world testbed.
- The sensor deployment was also considered a success regarding integration between public and private sector. The use of the deployed sensors has now been integrated into the municipality's strategic plan,[41] the Santander Masterplan for Innovation and the Santander Smart City Plan.
- The city is considered a unique area where the simultaneous deployment of technological devices has created an atmosphere where experimentation and service delivery can coexist.[42]
- It is also claimed (by McKinsey) that the development of Santander as a smart city (enabled by the real-world testbed) has enabled the business and entrepreneurial ecosystem to be revitalised. It has led to increased internationalisation, attraction of investment, consolidation of research and development activities, and more efficient urban services such as waste management.[43]

References

Galache, J., Guiterrez, V., Santana, J., Sanchez, L., Sotres, P., Casanueva, J., Munoz, L. (2014) *SmartSantander: IoT Experimentation over a Smart City Testbed*. University of Cantabria, Lancaster University, University of Surrey, Ericsson Serbia, Research Academic Computer Technology Institute of Greece, University of Lubeck.

Smart Santander – Telefonica (2015) https://iot.telefonica.com/multimedia-resources/smart-santander

Smart Santander Tutorial (2014) http://www.smartsantander.eu/downloads/Deliverables/smartsantander-tutorial.pdf

Smart Santander Website: http://www.smartsantander.eu

Interviews

Luiz Muñoz, Head of Coordination of SmartSantander, University of Cantabria.

2.4 Testbed Sweden – key facts

Description

Sweden ranks highly on global rankings for innovation.[44] A central element of the country's ability to innovate is the rich 'test and demonstration infrastructure', where firms, researchers and other users can test, verify and demonstrate new processes, products and services. Approximately 40 per cent of the 191[45] registered testbeds are real-world testbeds, which is also the area that is seeing most growth. The testbeds are mainly spread across topics such as product and production methods, energy, transport, environmental science, construction, health, automation, ICT, life sciences and community development.[46]

The Testbed Sweden strategy is a focal area within the overarching Smart Industrialisation Strategy for Sweden from 2016. The aim is to coordinate the existing testbeds better and establish new facilities that can solve societal problems. Testbeds are reviewed as a potential contribution to closing 'the valley of death' for firms and incentivising investments in R&D. It also aims to contribute to lessening institutional barriers to testing and demonstration through smart policy development. Vinnova, Sweden's innovation agency, has a mission from the government to establish a national function to coordinate Testbed Sweden.

Facilitator

Swedish Government, carried out by Vinnova, Business Sweden and the Research Institute of Sweden (RISE).

Purpose

The Testbed Sweden Strategy aims to narrow the 'valley of death' for firms, caused by the lack of risk capital and decrease in business R&D investments (as a percentage of GDP). The strategy also aims to strengthen the competitiveness for Swedish industry/academy/institutes and make a 'bulk' testbed ecosystem that provides mutual learning and better services for users.

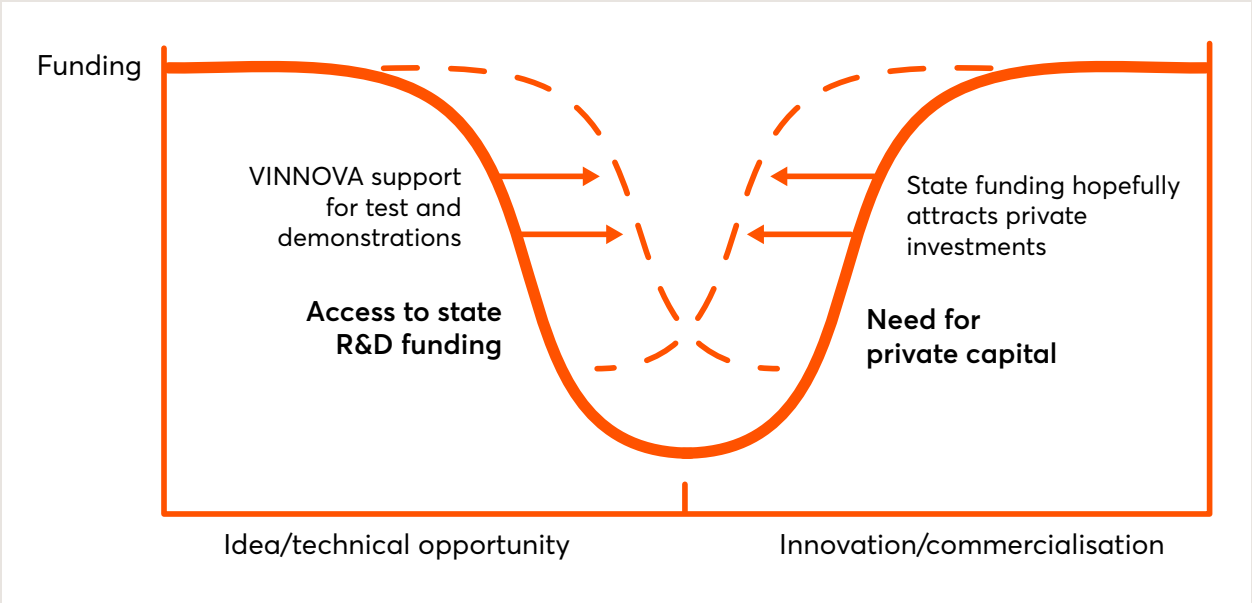
Actors involved in testbeds: In the Swedish case, there are a great variety of actors involved in testbeds. The private sector is the largest category, investing the most in testing and demonstration facilities. The Research Institute of Sweden (RISE) is the largest single actor in terms of ownership, operation and participation in testbeds, along with other public bodies involved in a variety of ways. Vinnova, the state innovation agency, spends about 100 million SEK (£82 million) annually on test and demonstration purposes. 60-70 per cent of Vinnova's funding goes to projects involving test and demonstration activities, and 2-3 per cent of the funding goes into these facilities themselves. Tillvaxtverket, the agency for economic and regional growth, contributes to establishment, use and accessibility funding for testbeds, for example through the 'Rural Testbeds' with a budget of approximately £85 million. The National Energy Body is also a core funder of small and large testing facilities, as is Business Sweden, who received a mission from the government in 2016 to market testbeds and facilitate inward investment.

Core lesson – responding to market failures

The idea to take a national approach to testbed funding and coordination in Sweden came about for several reasons. According to our interviewees, the primary purpose of this approach was to respond to two specific market failures:

- Closing the 'valley of death' for firms and incentivising R&D spending, which had been decreasing

Figure 7: Closing the valley of death for firms, adaptation of Vinnova model (2018)



As Figure 7: Closing the valley of death for firms, adaptation of Vinnova model (2018) shows, the idea is that public funding and coordinating testbeds will incentivise firms to bring their ideas and technical opportunities closer to innovation and commercialisation. This progress, made possible by public funding, is then meant to incentivise private capital investments at an earlier stage, with more mature ideas and technologies. The 'valley of death' will still exist, however with a narrower gap. The reason for selecting to invest increasingly in testbeds is due to their capability to support several firms and technologies. Coordinated, they are also capable of learning from one another and being marketed more efficiently.

The testbed strategy also aims to contribute towards several other benefits and secondary purposes, amongst others:

- The need for quicker iterations of trends through real-world testing facilities.
- Better connection between large firms and SMEs/Startups.
- Better coordination of the 'problem-owners' and the industry/academy/institutes.
- Achieving more cross-fertilisation of sectors.
- Knowledge transfer between testbeds.
- Attract investments and more testing and demonstration activities.
- Creating a common framework.

Other lessons learned

Involving the users of testbeds

Involving users is fundamental for testbeds to ensure demand and usefulness. The lack of dialogue with potential users risks design of unsustainable testbeds by not responding to demand.

- **Flexibility**: There are strong indications that attractive testbeds rely on flexibility, taking the user's needs into account in addition to collaborating in the design, development and operational phase. The type of involvement, and indeed who the user is, depend on the testbed function and characteristics.
- **Long-term funding and engagement**: The attraction and success of a testbed further depend on a driving partner (project coordinator) investing significant time and resources in creating complex and heterogenous constellations of actors, to ensure engagement and co-funding. Creating these constellations can take time, which needs to be accounted for.
- **Clear objectives**: Insecurity in terms of the expectations of use and the clarity of the objectives can be barriers to sustainable development of testbeds.
- **Ownership from users**: Real-world testbeds see the participation of users in the operational phase as a core element. The ambition of the Testbed Sweden Strategy is to facilitate this category in particular, focussing on collaboration.
- **Setting requirements**: Public support of testbed development should set requirements for the user participations, with varied engagement depending on the purpose of the individual testbed.
- **Ensuring the capacity of the testbed is fully exploited**: Many Swedish testbeds only utilise about 50 per cent of their full capacity. This is an area that can often be neglected: make sure plans exist for full exploitation of the testbed to make the most of the investment.

Engaging SMEs

Involving SMEs in testbeds is also an important element; however, this does not necessarily happen naturally, and they are not always in the target group of testbeds. SMEs often struggle with resources to be able to test their technologies and commercialise their innovation or access testbeds if they are not customised.

There are several factors that influence a testbed's accessibility for SMEs. Table 2 illustrates some known challenges and possible solutions to SME engagement.

Table 2: Challenges and solutions for SME engagement with testbeds

Challenge for SMEs	Potential solutions
The testbed is too costly for participation.	Subsidising the participation of SMEs either directly or through challenge funding earmarked for a certain type of innovator. Providing SMEs with free access to the real-world testbed.
Lack of knowledge about real-world testbed opportunities for relevant SMEs, or doubt in the worthiness of the testbed participation.	Having part of the real-world testbed budget earmarked for marketing purposes. Creating support structures for SMEs that increase their potential benefits and outputs.
SMEs not the primary target group.	As many real-world testbeds may prefer to work with large companies, those that involve SMEs, or plan to do so, can be rewarded or gain preference in funding applications. Smaller innovators can be involved through working methods such as workshops or labs concerning the real-world testbed topic.
Fear of exposing their products/ processes.	Having clear frameworks on Intellectual Property (IP) implications and building trust and transparency within the testbed.

Public sector involvement

One of the objectives of the Swedish Testbed Strategy is to increase the number of public sector bodies that own and operate testbeds. The reasoning behind this is that testbeds are tools that can lead to better public services and that publicly run testbeds have a higher probability of retaining and spreading the knowledge produced in them. Currently, only about 10 per cent of Swedish testbeds are publicly driven. However, they are nearly always involved in real-world testbeds. Barriers to public sector involvement are recognised to be resistance to change, laws and regulation, time and resources, and knowledge of testbeds as a tool.

Vinnova points to two distinct roles the public sector plays in the development of real-world testbeds:

- Providing access to public infrastructure (Schools, hospitals, land, roads, water infrastructure etc.).
- Facilitating solutions to public sector related challenges.

Vinnova further argues that:

- Doing testbeds within the public sector with a distinct focus on learning can facilitate more public innovation.
- Testbeds can increase the use and usefulness of already available public infrastructure.
- Public sector driven testbeds can lead to an improved regulatory environment.

Coordination of existing testbeds funded by the public sector is also key. Sweden already has a rich 'innovation infrastructure' and aims to coordinate them better to allow sharing of knowledge and resources. For countries/places with fewer testbeds, early facilitation of such collaboration, before set patterns of behaviour and organisation are set, can make the innovation system more robust in the future. Coordination could also be done at an international level.

Smart policymaking

Policymaking and regulation is a key part of the innovation system, and having regulatory bodies understand their part is vital for a flexible and well-functioning regulatory system in a fast-changing technological world. The use of 'policy labs' or 'smart policymaking' is an important part of the Swedish Testbed Strategy.

A policy lab is a group of actors with different skills aiming to develop regulation. The policy lab uses a set of user-centred methods and competencies to test, experiment and learn in policy development. These can be integrated within testbeds for specific cases or sectors, or they can be long-term constellations working with policy development over time.

Impact

- In a review of the testbeds involved in health and social care, several of the testbeds involved could showcase several implemented products and services within their respective areas as a direct cause of the testing activity. Other products or services have been deemed unready for implementation, due to incompatibility with the current system, and are envisioned not to be implemented for decades. These are both valuable results that would perhaps have been misjudged without testing in the environment in which the innovation was meant to be used.
- Evaluation of testbeds in the health and care sector is collectively deemed to show a high degree of coordination between the actors involved, and that it is focused on tackling mutual challenges.
- Many testbeds were evaluated to have found a good balance between the need of the public and the private sector, allowing both participants to advance further and achieve objectives and aims.

- In testbeds operating in construction and environmental technique, several testbed operators emphasise the non-material value of the testbed's function as a meeting place and collaboration platform, where participating innovators and actors can exchange ideas and experiences or find new collaborations and business opportunities. They also provide innovators with an opportunity to show themselves, their products or services through a testbed's wider marketing – acting as 'storefronts' to SMEs. Some also offer extended support to SMEs, such as Hammarby Sjorstadverk, which provides expertise in onsite cleaning technology, or Solar testbed, which provides support for developing ideas and writing applications, mentoring and idea development – although this is rare.

References

Interviews with

Fillip Kjeldgren, Head of Testbeds at Vinnova

Thomas Sunden, Project Manager, Sustainable Innovation

Literature

Ministry of Enterprise and Innovation (2018) *Why testbeds are important for attraction?*

Vinnova (2017) Testbeds within health, social and elderly care – a portfolio analysis.

Swedish Testbeds (2019) https://swedishtestbeds.com/en/about-swedish-testbeds/

Vinnova (2015) *Mapping and needs audit of test and demonstration infrastructure*. (Report in Swedish)

Vinnova (2019) *A study within the creation of the national function of Testbed Sweden – a study of the foundations of suggestions made to promote Testbed Sweden*. (Report in Swedish).

Vinnova (2019) Testbed Sweden – Filip Kjellgren

https://www.government.se/498615/contentassets/3be3b6421c034b038dae4a7ad75f2f54/nist_statsformat_160420_eng_webb.pdf

2.5 Testbed Gothenburg – key facts

Description

Testbed Gothenburg is part of the Testbed Sweden strategy as a response to the Smart Industrialisation Strategy for Sweden. Testbed Gothenburg is an initiative that enables an overarching initiative to bring together industry, academia, institutes and the city. It encompasses actors across the city in trade and industry, the public sector, academia, research institutes and science parks.

In recent years, Gothenburg-based companies have invested heavily in the region and in developing new products and services. One-third of Sweden's private R&D investments are made in Västra Götaland, a county in Gothenburg. Global brands such as AstraZeneca and the Volvo Group have invested heavily in the region and have contributed to Testbed Gothenburg.

Facilitator

Testbed Gothenburg was initiated by the City of Gothenburg through Business Region Göteborg, RISE Research Institutes of Sweden, Chalmers University of Technology and Gothenburg University. Business Region Göteborg is responsible for the business development of the 13 municipalities in the Gothenburg region.

Purpose

Testbed Gothenburg aims to accelerate economic development and build capacity and ability for testing innovation for firms and research institutes, as well as freeing up resources to proactively address tomorrow's challenges. Testbed Gothenburg advertises the city as an open environment in which companies can test their products before investing in full-scale development.

What is being tested

There are four different 'types' of testbeds and facilities advertised within the Testbed Gothenburg Programme:

1. **Academic environment**: (E.g. universities/research institutes) who own and fund the testbeds.
2. **Virtual testbeds**: (Funding from academia and industry) e.g. Volvo car and Volvo group use virtual testing environments to launch new vehicles;
3. **Living labs**: Areas within the city that work with citizens to co-develop products and services.
4. **Policy labs**: Where infrastructure of knowledge and competence is used to address policy issues (e.g. autonomous driving) that will require regulatory intervention.

The target industries for Gothenbrug are **the automotive industry, life science, urban development and logistics**.

One of the most well known testbeds is Electricity – a bus route that offers quiet, exhaust-free buses that pick up passengers indoors and are powered by electricity from renewable sources.

Core lesson – create a strong network

Feedback from Testbed Gothenburg has emphasised the importance of ensuring clarity and a strong, shared message for marketing between all partners. The success of the testbed programme is owed to the strong relationships between Gothenburg City Region and influential private sector partners. Business Region Göteborg has created a business directory on its website, which allows users to find and connect with partners they may be interested in working with.

Companies such as AstraZeneca and the Volvo Group have a strong sense of pride in the city region and are happy to invest and grow their offices in Gothenburg. This, coupled with the City's openness to invest and facilitate innovation, has built a strong network between the private and public sectors and academia.

Other lessons learned

Clarity of purpose

Through interviews, it was made clear that cities should be clear on their target industries and areas of growth. Gothenburg has advertised its key areas of opportunity as automotive, life science, urban development and logistics. Also, these target industries should be rooted in key sectors of economic strength or growth in the area.

The automotive industry in Gothenburg employs around 30,000 people directly and, when it comes to vehicle development, is one of the most knowledge-intensive per capita. Business Region Göteborg employs an expert in this sector to facilitate links between potential investors, the public sector and academic institutions.

Engagement with SMEs

While engaging SMEs is an aim of the testbed programme, anecdotal evidence suggests that engagement with SMEs has been a challenge for Business Region Göteborg. Due to the number of high-profile large organisations already in the region, the majority of collaboration has been with those already 'set up' to invest in the region.

Through our interviews, it was made clear that engagement with SMEs is a key target area for Gothenburg. The website includes resources for starting and growing a business, as well as providing networking opportunities for SMEs to meet potential investors and business partners. Business Region Göteborg offers services such as finance support and seminars to support business growth. The next step is to facilitate a route to get involved in the testbed programme, which may require significant capital investment up front.

Some of the key challenges for SMEs that Testbed Gothenburg is trying to solve are:

- Funding to participate in a testbed.
- Lack of networking opportunities.
- Lack of experience (compared to established global businesses).

Challenge: taking the testbed international

Evidence from interviews suggests that the industrial system in Sweden makes it challenging to take an idea tested in Gothenburg to a global scale. It appears that funding may run out once a testbed is deemed as completed, leaving a lack of funding to market the product on a global scale. As described in the Testbed Sweden case study, products require capital to ensure commercialisation on a larger scale. This is mainly a problem for SMEs and less internationally-established companies.

References

Interviews with

Maria Stromberg, Programme Manager and Head of Department Clusters and Innovation, Business Region Göteborg

Literature

Invest in Gothenburg website – an outline of current testbeds and learning https://www.investingothenburg.com/target-industries

Business Region Göteborg exhibition at MIPIM 2019 https://www.gothenburgatmipim.com

Business Region Göteborg website (business support) https://www.businessregiongoteborg.se/en

Endnotes

1. This is a sample of testbeds operating in the real-world environment from around the world. It is by no means exhaustive, and it is based on a number we have been able to identify in our desk-based research. There are most examples from the Nordics (Sweden in particular) and the UK, both due to better knowledge of relevant institutions, and the level of promotion of the testbeds.
2. Mustonen (2016) quoted from City Digest: https://www.citiesdigest.com/2016/12/19/smart-city-kalasatama-a-smart-district-aimed-at-saving-citizens-1-hour-per-day/
3. Thomke, S. and Bell, D.E., 2001. Sequential testing in product development. Management Science, 47(2), pp.308-323.
4. Halpern, O., LeCavalier, J., Calvillo, N. and Pietsch, W., 2013. Test-bed urbanism. Public Culture, 25(2), pp.272-306.
5. Armstrong, H. and Rae, J., 2017. A working model for anticipatory regulation. London: Nesta.
6. Dodgson, M. and Gann, D., 2011. Technological innovation and complex systems in cities. Journal of Urban Technology, 18(3), pp.101-113.
7. OECD (2019) Digital Innovation: Seizing Policy Opportunities. OECD, Paris.
8. https://www.nesta.org.uk/report/edtech-testbeds/ Batty, Florescu, Wong and Sharples (2019): EdTech testbeds: models for improving evidence. London: Nesta.
9. Bulkeley, H., Marvin, S., Palgan, Y.V., McCormick, K., Breitfuss-Loidl, M., Mai, L., von Wirth, T. and Frantzeskaki, N., 2018. Urban living laboratories: Conducting the experimental city? European Urban and Regional Studies, forthcoming.
10. Vinnova: https://www.vinnova.se/en/m/testbed-sweden
11. Ibid.
12. Ibid.
13. Ribiere, V. and Tuggle, F. (2010) 'Fostering innovation with KM 2.0.' VINE, Vol. 40 Issue: 1, pp.90-101.
14. European Network of Living Labs: https://enoll.org/about-us
15. See Appendix 3 for an overview of collected definitions from literature.
16. General Motors (1928), 'The Proving Ground for the Products of General Motors.' https://www.gmheritagecenter.com/docs/gmheritage-archive/historical-brochures/GM_Pr oving_Gr
17. Sidewalk Toronto Project Update (2019) https://sidewalktoronto.ca/wp-content/uploads/2019/02/FEB14-SWTO-Business-Case-Overview.pdf
18. Nesta (2019) 'Renewing regulation: anticipatory regulation in an age of disruption.'
19. Due to the recent history of this RWT, there is no full case study in Appendix 2.
20. https://meco.gouvernement.lu/dam-assets/publications/brochures---livres/2018-05-08-concept-digital-test-bed-ger-fra-lux-v1.pdf
21. We recognise that these are public services in some countries, and privately run by others. This report focuses on these services run by public bodies, however, many of the recommendations and descriptions can be useful to service providers in the private or not-for-profit sector also.
22. Research and Development.
23. The 'valley of death' is a common term with innovators, referring to the difficulty of covering the negative cash flow in the early stages of a start-up, before their new product or service is bringing in revenue from real customers.

24. United Nations (2018) 'Frontier Technologies for sustainable development in Asia and the Pacific.'
25. https://www.telefonica.com/en/web/public-policy/blog/article/-/blogs/the-european-commission-considers-that-the-smartsantander-project-has-exceeded-expectations-
26. Based on interviews with Vinnova and Testbed Gothenburg.
27. The Open University, University of Bedfordshire, University of Cambridge.
28. E-On, Huawei, Samsung, Tech Mahindra, ThngWorx, Privitar, Comarch.
29. UK Huawei 'Smart Cities Index.' (2018).
30. 'Smart Cities Special: Why Milton Keynes is more than just roundabouts.' (2018). https://www.cips.org/en/supply-management/analysis/2018/september/smart-cities-special-more-than-just-roundabouts
31. 'The future of mobility? In Milton Keynes it's already here.' (2018). https://spectrum.ieee.org/cars-that-think/transportation/self-driving/model-town-plans-next-steps-beyond-uk-autonomous-car-project
32. Interview with head of Transport Innovation, Brian Mathews.
33. General Data Protection Regulation.
34. 'Evaluation of the NHS England Innovation Test Bed at Care City.' Report prepared by Ann Raymond, Sachin Vadgama, Sonya Crowe, Steve Morris and Martin Utley at UCL.
35. Findings from interviews with Testbed Programme SROs.
36. NHS Test Beds: Testing innovations in real world settings (2018) Health and Care Innovation Expo.
37. This case study mainly focusses on experiences from the city of Santander, Spain.
38. Interview with Prof. Luis Muñoz, Project Coordinator and Lead from University of Cantabria.
39. McKinsey Global Institute (2018) 'Smart Cities: Digital Solutions for a more Livable Future.'
40. Sensors, communication, open data portal.
41. Strategic plan for Santander 2010-2020.
42. McKinsey Global Institute (2018) 'Smart Cities: Digital Solutions for a more Livable Future.'
43. Ibid.
44. Second place in 'The Global Innovation Index.' (2016). 'Sixth in the Global Competitiveness Report.' (2016-2017) and First in 'The European Innovation Scoreboard.' (2016).
45. There are more than 191 test and demonstration facilities, however, the 191 fall within the three categories of testbeds developed by Vinnova (Laboratory, simulated and real-world environment). There are several others that e.g. facilitate testing only for one company or that test something only once, which are not taken into account in this number.
46. Vinnova Analysis (2015).

58 Victoria Embankment
London EC4Y 0DS

+44 (0)20 7438 2500
information@nesta.org.uk
@nesta_uk
www.facebook.com/nesta.uk
www.nesta.org.uk

Nesta is a registered charity in England and Wales with company number 7706036 and charity number 1144091.
Registered as a charity in Scotland number SCO42833. Registered office: 58 Victoria Embankment, London, EC4Y 0DS.