A Compilation of Testbed Results – Summary

Industrial Internet Consortium (IIC) testbeds have special conditions and specific goals based on the interests of the end users who fund them. Many of the results from the testbeds are based on the initial business objectives, but there's also knowledge that can be used for more than the primary ecosystem. These learnings are valuable for developing Industrial Internet of Things (IIoT) pilots and projects. Most testbeds include similar challenges and risks during the deployment process. These are relevant to any IIoT projects within and outside the IIC.

Learnings regarding the development and deployment of a testbed that apply across many testbeds are called *horizontal learnings*. In contrast, *solution-centric learnings* drive the project and attract the attention of the stakeholders in that specific business or industry. Some learnings are both solution-centric and horizontal: these include learnings about deploying similar technology usages in other projects, yet they depend on challenges and conditions that are more or less specific to each testbed.

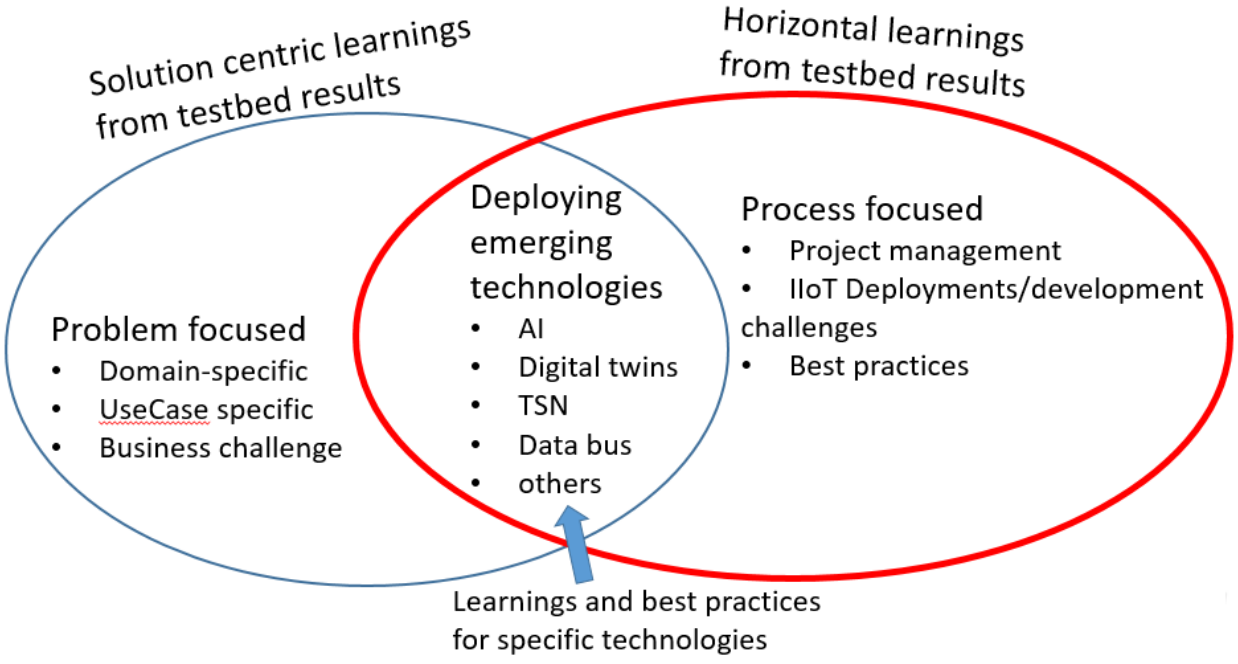

Figure 1: Solution-centric testbed results and horizontal testbed results

This short paper summarizes published horizontal learnings from several testbeds; they are expected to be applicable to a wide range of IIoT projects. We also describe the usage of technologies and typical challenges and mistakes to avoid.

For a full description of all learnings, please see A Compilation of Testbed Results: Toward Best Practices for Developing and Deploying IIoT Solutions.

THE PROJECT MANAGEMENT ASPECT

The value of partnerships: the testbed initiators knew early on that the success of their project depends on the quality of their team and its range of skills. Yet several teams realized that they had underestimated the value of a well-rounded team of partners and their cooperation. Developing an IIoT solution requires a wide range of functions and skills. The teams learned how to build and manage a partnership of experts in different areas of an IIoT solution and from various backgrounds. They had to learn how to adjust testbed goals so that every party is motivated with respect to their own objectives, combining product and technology testing with business goals, and accommodating short-term and long-term interests.

Defining requirements and setting goals: requirements are seldom stable--even more so in an experimental IIoT project. At first, they will be defined based on a combination of goals and constraints. Business goals are naturally the main driver, yet their modalities in the field can be diverse. Many constraints come into play that could derail the project if ignored, such as:

- the necessity to demonstrate value in the short term (a major factor),
- technical and operational feasibility,
- tolerable disruption in field operations,
- respecting the interests of all parties involved
- and long-term prospects.

These take some time to uncover and deliberate over.

The teams learned the value of recognizing non-functional concerns from end users (especially disruption to existing operations, training needs or security needs) as first-class objectives, and how to mix short-term and long-term goals.

Managing the testbed project: The teams learned how to phase their project (investigation, then pilot), how to set goals and how to manage expectations for all stakeholders. They learned the value in developing and testing as early as possible within the real operational context, and how to deal with related challenges such as minimizing disruption, involving field experts and communicating with the end user. Testbed teams learned the value of setting milestones precisely enough to be measurable so that everyone is on the same page, while phasing the testbed progression so that a radical change in directions is possible and accepted if needed. They also learned how to manage a partnership, which may change or have a different lead over time from one phase of the project to the other. A key factor was communication between partners, with a clearly identified lead for each partner.

CHOOSING, DEPLOYING AND USING SPECIFIC TECHNOLOGIES

Standards and their value: Testbed teams realized the value of using standards when available. They observed that standards bring more confidence to end users on the long-term viability of their solution regarding its scalability and its interoperability. Teams realized the value of their testbeds in generating requirements for standards to accommodate integration concerns better, such as how to combine different geolocation standards for asset localization, or what quality of service parameters are important for existing standards, such as the Time-Sensitive Networking standard. They realized an implemented testbed using a standard has considerable weight for standard organizations when endorsed by a team of experts under a recognized consortium.

Deploying specific technologies such as AI: While initially confined to a couple of testbeds, the evaluation and deployment of deep-learning and machine-learning technologies spread to several testbeds over time. The teams learned how to select the right AI technique for the problem at hand. They realized the value of field experts, their role in limiting the amount of relevant data to process and in overcoming issues with unsupervised learning. Teams realized the importance of focusing on data acquisition and quality, often relative to the operational context of AI. They learned the importance of phasing AI deployments and of testing in the operational environment. They also learned how best to position the value of AI in the field and gained insights on expected benefits of AI-enabled automation, such as reliability and scalability of operations.

Developing and using IoT platforms: The IIC testbed program has a well-rounded approach to platforms. Some testbed teams were involved as IoT platform providers. Carefully selected IIoT platform technologies enable rapid development and delivery of testbeds and IIoT solutions. Selecting from available off-the-shelf platform solutions lets developers focus on the problem at hand rather than struggle with custom solutions, setting up the infrastructure and required standard services. Hence, the testbed program recommends their use. In some cases, platform products are offered to testbed teams, with incentives, to encourage adoption, accelerate development and use of vendor products and open source components. The program also facilitates a smooth transition between testbed phases, such as testing, pilot and solution rollout.

Platforms can spread cost across several applications and users can leverage what has been developed before. Those testbeds that developed platforms shared the motivation of building an infrastructure open to adding future services, removing the technology expertise barriers for end users and relieving the end user of the burden of managing a solution for IT. Because additional investment is needed when developing your own platform, testbed teams had to justify the vision for the long term and establish the value of a platform as opposed to point solutions.

CHALLENGES

Dealing with brownfield challenges: testbed teams learned how to address the heterogeneity and retrofitting challenges of legacy equipment and how to circumvent the difficulty of collecting

data from these. However, given the cost and technical challenges some teams also questioned the need to deploy large numbers of sensors, and learned how to get around data acquisition constraints in various ways, including the combination of technologies and standards or refined analytics models. Teams learned the importance of capturing the operational context of data collected, in industrial environments, and how to do this for example with the use and analysis of video capturing.

Different understandings from different sides: The known divide between operational technologies (OT) and information technologies (IT) was a recurring issue. Best practices identified by the testbed teams include:

- test on the production site as early as possible,
- define an investigation phase,
- align everyone's expectations around clear and measurable objectives at each step,
- involve domain experts in the field and recognizing their value
- and a tight management of the partners team.

The misunderstanding gap extended to other parties such as technology vendors who needed to be educated about industry-specific requirements, particularly in terms of regulations, policies and compliance.

Discovering and articulating the business value and its evolution: Testbeds teams realized the importance of experimenting with the business model, not just the technologies. They discovered new business opportunities as testbed development progressed.

As there is no end to the scope of IoT-based enhancements in a field of applications, deciding on priorities and project limits must rely on a tight and continuous association between business considerations and technology deployment in the field. The organizational aspect must always be kept in sight. One learning of particular significance is to identify opportunities first that help the people on the shop floor gain more visibility into existing operations and enabling field operators. That field operators can see the value of the technology and view it as less threatening to their jobs. This proved to be a necessary step toward further automation or advanced asset management such as predictive maintenance.

The teams realized the importance of quantifying the business benefits with the customers, while remaining flexible: expected business value in several cases evolved over time. This means beginning with projects that deliver immediate value, in contrast as attempting more ambitious automation. A popular goal has also been to improve challenging manufacturing cases such as highly customized, small production lots, or high-mix assembly, as at present these often generate too low or no profits.

MISTAKES

Several testbed teams identified bad decisions they made or could have made. These are not independent: avoiding one will help avoiding others--especially in the order they are listed below. The following "mistakes" stood out:

Mistake 1: Treating the end user as a customer and not as a partner. Customers may not have a clear idea where or how IIoT can help, but they have key knowledge of their operations, a practical grasp on what can be done or should be avoided and the expertise to judge the value of a solution. All this customer knowledge emerges over time, as customer themselves may not be aware of what is important to communicate. Initial problem statements can be deceptive. This knowledge will be ignored for too long if end user is confined to the passive role of a customer. Technology providers in the team realized how important it was to warn end-users that their solution is unique, and they are not just customers, but partners in building it.

Mistake 2: Not spending enough time with the end user early on. Projects driven by technology providers tend to prioritize technical accomplishments over a deeper understanding of both short term and long-term end user requirements. This in turn decides where time is spent. Teams wished they had spent more time understanding the deeper rationale behind end user requirements, and the hidden constraints and cost their solutions would face or generate. They wish they had engaged customers earlier in the testbed process.

Mistake 3: Committing too early to operational objectives or business benefits. Overcommitting with insufficient knowledge of the operational context risks disappointing everyone in case of failure and gives the impression that either the technology is immature or that you have not mastered it in real environments. When there are too many unknown variables it is more prudent to limit initial goals to a carefully delimited investigation phase, and to take time to clarify all hidden constraints, disruptions and costs, involving end users and their management in decisions.

Mistake 4: Failure to define clear criteria for evaluating success risks, misunderstanding the goals and misaligned expectations from the stakeholders. Once the approach to developing a solution has been clarified, clear criteria for success must be defined and agreed by all parties, phase by phase. While keeping open the subsequent phases of a project based on the results of the current phase, all parties must be on the same page regarding the current phase goals. Time must be spent defining the metrics for success and effort must be

All testbeds are different, but they face similar challenges and have addressed them in comparable ways. The wide range of IIC testbeds has provided useful insights. Reflecting on their own process is often seen as less worthy of attention than the business goals that they were tasked to achieve, yet the collected learnings, challenges and mistakes from testbeds can aid most IIoT projects. A detailed analysis of this study is found in "A Compilation of Testbed Results" document.

made to collect these metrics such as monitoring the current operations and clearly defining the scope of the testing.