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Abstract. This paper reports on the process of designing an Antimicrobial Resistance (AMR) surveillance platform based on expertise from multidisciplinary approach involving informatics, infectious diseases and global health. Conceptualizing the surveillance platform as an Information Infrastructure (II), we draw upon design principles for its development based on the free and open source digital platform - DHIS2. We describe the scaling process over three action research cycles, with the learning from each cycle feeds into the other both practically and conceptually. The first two cycles are based in India, the first at the regional level of surveillance and the second at a hospital facility level. The third cycle concerns efforts to build global networks to facilitate scaling efforts. The paper builds learning around the design and development process, with a particular focus on functional and geographical scaling, contributing to building the information systems response to address a very urgent and fast rising global health challenge of AMR.

Keywords: Surveillance, Antimicrobial resistance, Information system, Information infrastructure, India

1. Introduction

Antimicrobial resistance (AMR) is a grand challenge of our times, and knowledge of the problem in different sectors is incomplete affecting multiple levels of society. As the former secretary general of the World Health Organization (WHO), M. Chan has said, this "slow moving tsunami" threatens us with "the end of modern medicine as we know it" [1]. The consequences of rising rates of AMR for human and animal health, for economies and for the environment seem dire, endangering the future of societies at large [2].

Since the late nineties, a number of global declarations and research publications have emphasized the need to strengthen interventions to combat AMR. Some examples of these global efforts include the World Health Assembly (WHA) Resolution of 1998 and the WHO Global Strategy for Containment of Antimicrobial Resistance published in 2001. In May 2015, the 68th WHA adopted the global action plan on AMR, and all member states were urged to implement National Action Plans (NAPs) by 2017. At present many countries have in place these plans, but what`s next? How these action plans get implemented in practice, particularly in health facilities in low- and middle-income countries (LMICs), which are at the forefront in engaging with the AMR challenge.

A key recommendation in the global and national action plans has been on ***strengthening the knowledge and evidence base through surveillance and research.*** However, along with high AMR burdens, LMICs continue to suffer from having the weakest surveillance systems. O'neill, [2] leading to a cycle of inadequate knowledge of AMR followed by poorly designed interventions without a scientific evidence base. Emergence and spread of AMR are the consequences. An important adverse consequence

of this is the misuse of antibiotics. In India for example, one of the countries with highest prevalence of resistant microorganisms, consumption of antibiotics increased by more than 100% over the period from 2000 to 2015 [3]. Information and communications technology (ICTs) play a key role in surveillance systems for making improvements at both the policy and clinical levels. At the policy level, surveillance can help in making better estimates of the location and volume of AMR, which can guide decisions related to resource allocation and building of regulatory frameworks. At the clinical level, effective surveillance is needed for targeted treatment, to help strengthen infection control practices, and to develop guidelines for antibiotic prescription practices. How do we break this vicious cycle and follow the science which emphatically has argued for strengthening surveillance in combating AMR? How can LMICs seek to be better prepared?

AMR represents a unique challenge concerning scale and dimensions. First is the geographical dimension, since AMR represents a national and global problem without any geographical constraints. Then the functional dimension since AMR surveillance is grounded within a One Health (OH) approach which acknowledges the interconnectedness of humans, animals, and the environment [4]. The AMR platform thus being used to develop surveillance for human domain, needs to be scalable to other domains of veterinary medicine and the environment.

This paper addresses the following research question:

What are approaches to design AMR surveillance systems for supporting geographical and functional scale?

In the next section, we discuss the AMR surveillance challenge, followed by a description of the methods and care study. The analysis and discussion section then follows. Finally, we present the conclusions.

2. The AMR surveillance design challenge

As one of the largest contemporary global health threats, AMR is estimated to contribute to annually 10 million deaths and a cost of 100 Trillion USD by 2050 [5]. The threat is aggravated by a 65% global increase in human antibiotic consumption during 2000-2015 and an 80% rise in the use of antibiotics in the animal sector [3].

While LMICs like India are considered global AMR hotspots, the magnitude of the problem is largely unknown because of the poor surveillance systems. The potential spread of AMR from such hotspots also represents a risk to low AMR prevalence countries like for example Norway. This threat arises from intensification of globalization processes exemplified by movements of more than 1 billion people across borders annually [6]., and a high number of tourists to the tropics being colonized by resistant microbes [7]. This require collaboration between physicians, veterinarians, informaticians and other related disciplines. Given the global and inter-connected nature of AMR, it becomes important to design AMR surveillance with scale in mind, to expand use across geographical regions and different domains.

A recent study demonstrated that LMICs have weak surveillance systems [8], making their strengthening an urgent development priority. In 2014, five of the 11 South East Asian Region Office (SEARO) countries (India, Bangladesh, Indonesia, Maldives, and East Timor) could not generate AMR data. Only Thailand and Nepal showed capacity to collect and collate data from more than five laboratory sites [9]. As a result, governments' possibilities are limited in establishing the epidemiological linkages between rampant use of antibiotics and AMR. There are two basic approaches to control AMR: technological solutions and curtailing consumption. Much attention has been given to efforts to produce technology, like novel antibiotics or rapid diagnostic tests. However, there is limited focus on strengthening surveillance systems, leading to minimal quality data on consumption and use.

While the importance of surveillance in the fight against AMR is universally acknowledged, less is discussed on how effective systems can be designed, implemented and scaled. This issue is particularly relevant in LMICs which often face a weak, if not absent, system of systematic reporting. It is a double burden, with countries who need AMR surveillance most are those who have the weakest systems. While this is the case for surveillance in human medicine, systems are even more limited and weak in the domains of animals and the environment. Integration of data across these domains is still only a far-away dream

Our work is grounded in India, where the challenge of scale is particularly acute, given the numbers of health facilities, the high population figures, and the high AMR prevalence. Many millions of people still lack access to relevant health services such as to effective antimicrobials and diagnostic facilities, and risk becoming impoverished because of health spending [4]. Rural communities in India, which typically are the source of emerging infectious diseases, are not able to access adequate diagnostics as microbiology testing facilities are available only in tertiary care facilities [9]. Samples from district hospitals (more than 800 in India) would need to be sent to the tertiary hospitals, representing a huge logistics challenge. Further, India suffers from drastic misuse and overuse of antibiotics, allowed to flourish in the absence of a regulatory frameworks and antibiotics usage guidelines [10]. Data reporting from private facilities to national systems is minimal, and very little is known about domains of agriculture and veterinary medicine [1].

Designing an AMR surveillance system for scale – across geographical and functional boundaries – represents a wicked problem in India and also globally. In this paper, we discuss how we are approaching this problem, even though we are at a very early stage in this process. To guide our design thinking, we are inspired by the Information Infrastructure theoretical perspective.

3. Conceptualizing the design challenge: An Information Infrastructure (II) perspective

Our design approach is guided by Information Infrastructure (II) theory, which helps understand the design and evolution strategies of large-scale, complex and distributed systems like the Internet and national health surveillance systems. IIs represent interconnected technical and institutional elements, without finite start and end dates, which are forever evolving. IIs are shared, and no one entity controls the whole infrastructure. The nature of heterogenous interconnections and their dynamic nature, make them complex, and tackled differently from traditional stand-alone systems [11], [12]. IIs involve multiple and heterogeneous stakeholders with asymmetric power relations , conflicting goals, requiring diverse and novel design approaches [13], [14].

An AMR surveillance platform within an OH framework needs to be conceptualized as an II, as it requires to manage data from multiple domains each with their own subsystems. These different components need to technically and institutionally work together, which is complex since each component is owned by different departments or entities (such as health or animal husbandry). II theory emphasizes the cross-boundary and disciplinary knowledge to "force unity from diversity, centralization in the face of pluralisms, and coherence from chaos" [15]. The analysis of the Internet based on II theory identified two fundamental challenges of bootstrapping and adaptability. Bootstrapping refers to the early phase of an II evolution when there are limited users, thus providing limited value in attracting new users, which constrain growth. The adaptability problem arises when an II grows into a large installed base, which constrains its adaptability to new situations, thus constraining the II evolution.

To deal with these two problems, [14]. proposed five design principles (DPs) which can serve as broad guidelines to approach II development, and help "formulate in concrete terms how to generate and select desired system features as to achieve stated system goals" (ibid, p.5). DP 1 is to design for direct usefulness by offering useful functionalities for a small group and without much a need of a large installed base. DP 2 is to build upon existing installed base by leveraging on existing functionalities to

create added values. DP 3 is to expand installed base by persuasive tactics to enrol new uses and users to generate momentum. To address the adaptability problem, DP 4 is to make the II as simple as possible, and DP 5 is to modularize the II, minimizing tightly coupled dependencies, and build buffers to minimize risks of full breakdowns when one part of the II malfunctions.

We will use these DPs as our initial guidelines, which we will customize, adapt and extend given the particularities of AMR surveillance and the specificities for the human domain, and its subsequent scaling to other contexts. In the course of applying these principles within an ongoing initiative we will identify different challenges experienced, and how we have tried to address them.

4. Research Methods

Methodologically, we draw upon an action research approach to the AMR platform design involving two levels of use: i) regional level, including a set of 27 facilities pan India reporting data into a surveillance platform; and ii) at the level of a public health facility, catering to the facility and lab specific requirements.

Specifically, we draw upon the Canonical Action Research approach [16]. which has the following characteristics: i) the research process takes place in collaboration with the research team and the organization (called client-system infrastructure) to solve a problem which the organization recognizes as significant; ii) the research process involves iterative action research cycles of problem definition, diagnosis and design of interventions, followed by implementation and assessment; iii) the research will be guided by a theory of change, in our case drawing from II, specifically relating to how to design and evolve IIs. The overall aim of the research initiative is to generate new theoretical (around design strategies) and practical (capacities to use the new system)) knowledge with each action research cycle which helps improve the subsequent one.

We describe our research in the form of three broad action research cycles: 1) designing and field testing the regional level surveillance platform; 2) adapting and extending the same platform suitable for a hospital facility; iii) building global networks to enable scaling across multiple contexts. As is common in action research, learnings from each cycle feed to improve subsequent cycles.

In the table below we summarize the timelines and data collection methods for the action research cycles.

Action research cycles	Timelines (for Human domain)	Key aim	Data collection methods	Data analysis methods
AR1: Regional level	July,18 – April, 19	Design of system for research and surveillance which aids in assessing severity of AMR at a macro level.	Using the existing system as a design reference to build the same system on a new platform; study of user manuals of existing system, focus group discussions, global/national workshops, discussions with AMR experts.	Guided by interpretive approach; identification of design related themes; relating these themes to Design Principles drawn from II
AR2: Facility level	March 19 – October, 19	Design of the surveillance system which support workflow of the microbiology lab in recording and reporting daily cultures done, enabling physicians to	Interviews and discussions with end users, namely the microbiologists, doctors and hospital administrators, and study of existing work flows and data collection forms	Guided by interpretive approach; identification of design related themes; relating these themes to Design Principles drawn from II

		make evidence-based decisions while prescribing antibiotics and conducting infection control activities		
AR3: Scaling strategies	Nov 19-ongoing	Building for scale to enable taking the platform to other locations in India and also globally	Study of technical documents; interaction with expert groups from WHO and Norwegian Institute of Public Health to gain understanding of scaling requirements	Guided by prototyping approaches in interaction with expert groups; building scaling design frameworks

Table 1: Timelines and data collection systems for the action research cycles.

5. Case study

The case study narrative concerns the building and scaling of the AMR surveillance platform on the free and open source DHIS2 platform. The DHIS2 is available to all without licensing encumbrances, thus positively enabling scaling efforts. The DHIS2 currently has high global legitimacy as a defacto standard for health information system (HIS) development [17], expressed through support of multiple global partnerships including WHO, Global Fund, UNICEF, NORAD and others, as a digital global public good (DGPG) to enable free and unencumbered access to countries. Given that DHIS2 finds wide-spread use in 80+ countries, it has a large installed base of supporting resources of capacity and infrastructure, which in the long run can be leveraged upon to strengthen AMR platform scaling. We now describe how the DHIS2 was developed upon across the three cycles.

Action research cycle 1 – the regional level: A national level research organization (anonymized as InMo) had since 2016 established an AMR surveillance network comprising of 27 specialty hospitals and private sector laboratories across India. The platform had been built in-house, and soon experienced functional scaling challenges, particularly related to analytics. InMo were already aware of DHIS2, and they decided to replicate their existing platform on DHIS2. InMo approached an Indian NGO (HISP India) to undertake this project, as they had long standing DHIS2 expertise and agreed to do the development without cost.

The NGO took an incremental design approach, by first replicating the existing data entry module in DHIS2, followed by the output module. Requirements were elicited through the study of the existing design documents, discussions with the developers and seeing system demos. The initial requirements were shared in the form of Excel sheets extracted from application's database. Data was organized in the form of masters in the database with different tables for organisms, antibiotics, breakpoints, sample and test types. Antibiotic panel masters were designed representing a combination of the logics to define what antibiotics to test for a particular organism.

A big challenge in our research was the inability of the system developers to meet the end users in the 27 network hospitals. InMo believed, since they had engaged with the users in building the first system, they were on top of the requirements, and HISP India only needed to interact with them. We found this thinking problematic, as we never heard the voices of the users and arguably many things were lost in translation. The prototypes which were replicated represented requirements of speciality hospitals and private sector labs. InMO made various requests to add or remove functionalities, and the planning was very adhoc causing frustration to the development team. For example, there was a demand to enable data sharing between the existing AMR surveillance platform WHONET used in multiple Indian facilities, and the platform we were developing. When we were told that the functionality developed initially did not fully support the data transfer process, we wanted to talk to the end user to understand the problem. This access was not granted, making it challenging and adding extra time to the

development process. To enable a degree of standardization of the nomenclature, we used the standard libraries available in WHONET for terminology/nomenclature for organisms, antibiotics, test types and results.

InMo would assure us that after a certain set of functionalities were completed, field testing would start. However, as the prototype was completed, the research team would ask for more functionalities to be added before commencing field testing. For example, integration with WHONET was one request and then there was a demand for a isolate transfer module to track samples from one lab to another for quality testing. This functionality followed the specific workflow that was imitated within the network, requiring a batch of samples sent each quarter from regional labs to the respective nodal lab for quality testing and reporting test results to the regional lab. These functionalities were not simple replications, but represented quite new requirements, which were difficult to understand and build, within very aggressive timeframes, and in the absence of direct interaction with the users and where In MO themselves were unclear of the requirements.

In summary, this action research cycle can be seen as a "top-down" approach where the end user voices were invisible. A key learning from this was understanding the limits of a top down model to system scaling. On the practical side, HISP India learnt about the AMR surveillance domain on which they had limited prior experience. Another key learning was the experience of extending the DHIS2 platform to use in the hitherto uncharted area of AMR surveillance. Even through the platform developed did not find active use amongst the existing 27 hospitals, but that does not discount the potential for future use here or in similar regional kind of settings.

***Action research cycle 2 – the health facility level*:** The rich experience gained in the first cycle was motivating to the NGO to approach a state government hospital facility to build an AMR surveillance platform for local use. Since the NGO had already been working in that particular state building hospital information systems, they carried the trust of the state who granted them ready access to design and implement the platform in one medical college facility. For the NGO, a starting point to this process was to develop a detailed understanding of the work and information flows on how AMR testing was carried out, and how data was collected, reported and used.

The initial idea was to design the system prototype based on the user requirements at the microbiology laboratory. During this process, the microbiologist and lab staff realized that in absence of protocols and experience of AMR data collection and reporting, articulating requirements was difficult. Hence, they suggested to start working on the prototype created in the first action research cycle, and in this process learn about the specific facility requirements and simultaneously enhance the platform. The prototype from the first cycle was demonstrated to the lab staff at the hospital facility but was found inadequate to their needs. While the concept behind reporting the information was similar to the regional system, it was not sufficient in supporting the clinical and laboratory work. The test results must enable the physician to optimize the treatment of the patient, while in the earlier system the aggregated data was to be used primarily to form a picture of the degree of AMR in the population at large. With this vision, development of the application at a facility level was started in collaboration with microbiology lab technical staff and has been going on for over a year now.

The hospital has now assigned two data entry operators to the microbiology department, who are responsible for entering data on a daily basis from Mondays to Saturdays. The data entry operators usually follow a weekly roster where specific days of the week are assigned to them. With the COVID-19 outbreak, data entry work was suspended from March for a few months, but now has regained full momentum since mid-July. About 20-25 records are being entered every day. As regular use has progressed, the hospital has made some requests for enhancing the application ranging from minor changes to the dashboards to major changes in the functionalities itself. Some of these changes include: i) fitting the list of organisms, antibiotics, phenotypic test types and organism groups (such as Streptococcus) to match their local needs; ii) adding location details (eg. OPD, IPD etc) to the existing tables in the dashboards; iii) changing the graphs and the tables from being organism-specific to sample

specific; iv) addition of some missing species in organism group list like pseudomonas spp. in NFGNB; and v) reconfiguring the data entry App which was earlier organism-specific to patient-centric by adding a patient reporting form that captures details like the name, age, gender and state. Work is ongoing to generate patient-specific output reports containing sample details and RIS(Resistant Intermediate Susceptible) graphs.

The table below summarizes some differences in requirements from the first to the second action research cycles.

AMR Surveillance system requirements	
Regional level	**Hospital facility level**
Application focused on a few groups of microorganisms.	Would need to report on all microorganisms isolated in the laboratory.
Specific antibiotics listed/tested for an organism species.	A flexible list of antibiotics was required to reflect current usage.
Specific organism groups were pre-defined	Organism regrouping was required based on laboratory requirements.
Antibiotic specific susceptibility tests results were analysed.	Analysis was based on class of antibiotics required. Segregation of oral and injectable drugs was required. Segregation and analysis of antibiotics based on the department they are used in the hospital was required. A combined report for all the above categories is required for a monthly analysis.
Application did not include other hospital/lab specific modules.	Sample collection, transfer to other labs and sending test results to physician electronically was essential.
Data validation at various levels was required.	Data validation/approval process not essential
Isolate transfer module was required to track sample transfer	This module was not required

Table 2: Requirements for an AMR surveillance system for research and clinical perspective.

After few rounds of continuous interactions with the lab users, the module has been periodically updated, and the platform is now under routine use in the facility.

Action research cycle 3 - Building global networks to enable scale: As the platform has got stabilized with continuous use and system upgrades, there has been interest expressed by three global groups on the use of the platform, which has provided further impetus to enhance scale. The firs concerns the WHO AMR group in HQ, who were interested to see the potential of the platform being able to share data with their global system called Global Antimicrobial Resistance Surveillance System (GLASS). The second concerned a research group from Germany who were interested in seeing how this platform could be adapted and made relevant for 6 hospital facilities across 5 Sub-Saharan African countries. The third was the Norwegian Institute of Public Health who are exploring the possibility of using the platform at two levels of a hospital laboratory and at the regional level. In analysing these different requirements,

we saw that our system may be too “India specific” and needs to be made more generic. This has led to designing for scale through creating a number of enhancements, and by separating out the “core or essential” requirements, with that of the enhancements which different sites could use.

The first enhancement was the integration of the platform with WHONET, which is globally the most popularly used AMR system running in nearly 3000 facilities. By doing this integration, the users are given the choice of either using their existing WHONET platform and transfer the data to the DHIS2 platform for strengthening analytics and dissemination. However, completely changing from WHONET to the DHIS2, is also an option. The second was the integration with the WHO GLASS system, which would allow countries to report their national data to the global system. The third was to enhance the use of standards, which was carried out through the use of data standards from WHONET and also through the incorporation of the ICD11 standards.

To meet the requirements from the German research group, the NGO sought to improve their documentation, by clearly describing the “Baseline AMR surveillance system”, listing down the core and must-have functionalities required in a base system. This way, contexts who wanted to just use the essential features, could appropriately select. Secondly, the document also included the additional functionalities, which could be used by those who needed them. Thirdly, the document detailed the core functionalities of DHIS2, which could be further drawn upon to build new modules and functionalities (such as Android reporting). This document then provides a strategic approach to scale both functionally (more features) and also geographically (additional use contexts). Based on this strategic approach, the German research group has initiated a project to implement this platform in six hospitals spanning different countries in Sub-Saharan Africa. This effort will also be conducted in an action research mode, and the cycles of learning and improvements will continue in the future. With the Norwegian Institute of Public Health, the platform has been evaluated, and a research proposal has been formulated involving two levels of use, one, at the level of a hospital lab facility to collect lab data and transfer into another instance of the platform to enable regional and national level reporting.

All three streams of effort are in process, and should lead to further scaling as the systems get implemented on the ground.

6. Case analysis

The case study analysis is informed by the II theory’s DPs, which is drawn upon to examine the challenges and approaches used in our development approach across the three AR cycles.

DP1: Design for direct usefulness

This DP was difficult to apply in the regional system as we had no access to end users and our understanding of requirements was mediated through the InMo. While we did try to work around this problem by extensive study of documents and discussions with InMo, our understanding remained inadequate. As a result, we could not provide adequate functionalities at the initial level, which meant that we could not enrol new users. However, in the second cycle, we worked closely with users, understanding what was directly useful for them enabling us to provide for identified needs with requisite functionalities. In the third cycle, we had two key end users. One, was the WHO HQ, who were primarily keen to enable the integration with GLASS, which we could provide. The next steps are at present under consideration.

The other end user was the German research group, who have seen the relevance of the system for their project in Africa and are planning to proceed with the implementation. Based on the ongoing discussions and feedback from the AMR team at WHO HQ, the system will be developed for it to be able to follow global standards and terminologies like SNOMED CT. Country specific data reporting and analysis is essential to understand the regional and global AMR picture. The system will be

designed to allow countries to report different pathogens and include their list of antibiotics being tested for respective pathogens.

In the Indian context, the plan is to scale the application currently implemented at one facility to all 4 teaching hospitals of the state. To facilitate standardization, a baseline AMR instance has been developed with basic features and requirements to report, monitor, and analyze AMR data. Specific requirements from any facilities will be added on top of the baseline instance. Having the data reported on the same parameters, this will promote a standard usage of the data elements and provide a clear picture of the AMR situation in the state.

DP2: Build upon existing installed base

II theory guides us on the importance of the existing installed base and its both enabling and constraining influences. In the first cycle, the existing regional system represented the installed base, and it clearly had constraining influences on the development process. As the project mandate was clearly to replicate the existing system, we were forced to incorporate the existing design, including its inefficiencies. In the absence of our access to end users, we were not able to add improvements. In the second cycle, the installed base was the existing manual processes and the absence of a digital infrastructure. This base proved enabling, as we could provide value in improving the existing manual processes. The users saw this as being positive, and they increasingly showed more support and motivation to expand the project. In the third cycle, the existing GLASS system represented the installed base, and providing a data sharing mechanism represented a relatively structured and executable task, and potentially an enabling influence.

DP3: Expand installed base by persuasive tactics to enrol new uses and users to generate momentum

As discussed under DP1, our inability to access users in the regional system meant we could not enrol the end users to generate momentum for scaling. Under action research cycle 2, we have focussed primarily in the microbiology lab and have enrolled the microbiologists and technicians in the lab. There are at least two higher levels of users to be enrolled. One, is at the hospital level, so that the systems could also be made relevant for other departments like OPD, IPD, surgeries etc. Two, is at the state level, where systems developed and tested in this hospital could be shown to authorities to convince them to implement it in other hospitals. We have not achieved this level yet, but that is clearly the ambition. In the action research cycle 3, we are collaborating with WHO and expecting them to use their position of legitimacy and expertise to persuade country level users to explore this platform. The collaboration with the German group follows the same principle of drawing upon the legitimacy and expertise of an external partner to persuade end users and build momentum.

DP4: Make the II as simple as possible

The design process was both constrained and enabled by the DHIS2 core architecture, which places boundaries on what can be done or not. However, in the regional case, since the task was of replication rather than designing from scratch, we could not consciously design for simplicity. In the hospital facility case, keeping simplicity was a guiding principle and we tried to implement this by replicating the existing forms and workflows of the lab technicians, so that they did not feel they are dealing with something alien. In the scaling phase, we have tried to separate out the “simple” system through describing the baseline and detailing how it can be incrementally expanded based on needs.

DP5: Modularize the II

The DHIS2 has a modular structure, which was enabling in creating a modular AMR surveillance system. Further, we created separate Apps for data entry, outputs, isolate transfer, WHONET and

GLASS integration etc., to implement this modular structure. Applications for interoperability with other laboratory information systems have been developed.

6. Discussions and conclusions

Design Principles provided by II theory have been applied to analyse the design challenges relating to the scaling of an AMR platform. We had started with describing the scaling challenge to play out under the two dimensions of functionality and geography. The functional dimension has played out with different design requirements at the different levels of the regional and global facilities. Technically, these challenges have not been unsurmountable, and the DHIS2 platform, with its open source and modular architecture, allows for this functional scaling to be enabled. However, the organizational level conditions which limited access to end users greatly impeded the adoption and scaling process. So, scaling can never be seen as merely as a technical exercise, but needs to be considered in a holistic perspective.

We have realized the importance of creating a standardized approach to the collection, analysis, and sharing of AMR data at the country global level is essential to facilitate scaling. The current application follows WHO standards and uses the same codes for pathogens, antibiotics, and samples which makes it easier for integration with other applications and has a comprehensive list of pathogens and antibiotics that can be filtered out based on specific country requirements, thus allowing scalability for different pathogenicity. WHO encourages and facilitates the standardization of data in countries to get a whole picture of the AMR in a country. This country-specific information is imported to a global platform WHO GLASS, a platform for global data sharing on antimicrobial resistance (AMR which facilitates the AMR data analysis at a global level. To standardize the AMR data being collected, unique functionality of interoperability with WHONET, a free Windows-based database software developed for the management and analysis of microbiology laboratory data with a special focus on the analysis of antimicrobial susceptibility test results (the current WHO supported system) has been developed. This interoperability enables the potential for scaling across sites currently using WHONET. The development of a web-based utility for the integration of DHIS2 with GLASS is ongoing. This will enable the facilities using DHIS2 to submit data to GLASS which allows to shift from only reporting data from individual isolates towards including epidemiological, clinical, and population-level data. To promote standardization ICD 11 diagnostic codes for AMR have been configured in the application to improve decision-making and drive national, regional, and global actions.

References

1. Chan M., 2016 *WHO Director-General briefs UN on antimicrobial resistance*: WHO.

2. O'neill, J., 2016. Tackling drug-resistant infections globally: an overview of our *work*. The review on antimicrobial resistance. London: Wellcome Trust.

3. Essack SY, Desta AT, Abotsi RE, Agoba EE., 2017 *Antimicrobial resistance in the WHO African region: current status and roadmap for action.* Journal of public health. 1;39(1):8-13.

4. Heudorf, U., Krackhardt, B., Karathana, M., Kleinkauf, N. and Zinn, C., 2016. *Multidrug-resistant bacteria in unaccompanied refugee minors arriving in Frankfurt am Main, Germany*, October to November 2015. Eurosurveillance, 21(2).Main, Germany, Euro Surveill. 2016;21(2):pii=30109. https://doi.org/10.2807/1560-7917.ES.2016.21.2.30109

5. Klein, E.Y., Van Boeckel, T.P., Martinez, E.M., Pant, S., Gandra, S., Levin, S.A., Goossens, H. and Laxminarayan, R., 2018. *Global increase and geographic convergence in antibiotic consumption between 2000 and 2015*. Proceedings of the National Academy of Sciences, 115(15), pp.E3463-E3470.

6. The World Bank., 2017. *Drug-Resistant Infections: A Threat to Our Economic Future*.

7. de Smalen, Allard & Ghorab, Hatem & Ghany, Moataz & Hill-Cawthorne, Grant., 2016. *Refugees and antimicrobial resistance: A systematic review*. Travel Medicine and Infectious Disease. 15. 10.1016/j.tmaid.2016.12.001.

8. Singh, P.K., 2017. *A universal good: How increased health coverage can help beat back antimicrobial resistance*. World Health Organization, Regional Office for South-East Asia.

9. World Health Organization, 2017. *Tracking universal health coverage: 2017 global monitoring report.) global monitoring report. Geneva:* World Health Organization and International Bank for Reconstruction and Development/The World Bank; 2017
   http://pubdocs.worldbank.org/en/193371513169798347/2017-global-monitoring-report.pdf

10. World Health Organization, 2018. *A vision for primary health care in the 21st century: towards universal health coverage and the Sustainable Development Goals* (No. WHO/HIS/SDS/2018.15). World Health Organization.

11. Ciborra, Claudio U. et al., 2000. *From Control to Drift: The Dynamics of Corporate Information Infrastructures*. Oxford University Press, Inc. New York, NY, USA ©2000.

12. Hanseth, Ole and Kristin Braa. 2000. *"No Title."* in From Control to Drift: The Dynamics of Corporate Information Infrastructures, edited by C. U. Ciborra et al. Oxford University Press, Inc. New York, NY, USA ©2000.

13. Sahay, Sundeep, Eric Monteiro, and Margunn Aanestad., 2009. *"Toward a Political Perspective of Integration in Information Systems Research: The Case of Health Information Systems in India*." Information Technology for Development 15(2):83–94.

14. Hanseth, Ole and Lyytinen, Kalle. , 2003. *Theorizing about the design of Information Infrastructures*: design kernel theories and principles. 4.

15. Hughes, Thomas P. 1987. The evolution of large technological systems. In The social construction of technological systems. New directions in the sociology and history of technology, edited by W. E. Bijker, T. P. Hughes and T. Pinch. Cambridge, Massachusetts & London, England: MIT Press, 51-82.

16. Davison, R.M., Martinsons, M.G. and Ou, C.X., 2012. *The roles of theory in canonical action research*. MIS Quarterly, pp.763-786.

17. Sahay, Sundaraman, Braa, 2019 Public Health Informatics: *Designing for change - a developing country perspective;* OUP Oxford; ISBN-13: 978-0198758778