Robotics and automation within the Medicines Manufacturing community

Identifying gaps within the UK medicines manufacturing sector

February 2022

Executive Summary

Compared with other countries, the UK is lagging behind in the widespread adoption and deployment of automation and robotics across the Medicines Manufacturing industry[1]. To understand some of the reasons behind this, Innovate UK and KTN arranged a workshop, which was held on 1st February, to gain insight into what gaps exist and to begin to identify areas where innovation could help resolve these issues.

Over 40 individuals participated, from companies from across the industry, representing small, medium and large organisations, as well as academia and industrial catapults.

The workshop identified number of key areas for further attention, including:

- Integration and interoperability
- Data
- Skills

Gaining insight into where the gaps are provides information on where additional investment or innovation could unlock more widespread use of robotics and automation within medicines manufacturing. This insight will be used to identify common challenges which require additional outside support or innovation, and to shape the future of UKRI programmes and Medicines Manufacturing Industry Partnership Technology and Innovation strategy. The first step towards this is a second workshop, scheduled for 30th March at the University of Sheffield Advanced Manufacturing Research Centre (AMRC). This workshop will focus on how the industry can move from a manufacturing set-up which uses minimal software or automation, towards a highly integrated system where physical and virtual experiments are conducted in a single workflow.

It is apparent from the work so far that the challenges identified are common across multiple organisations, and the greatest impacts will be achieved with collaborative, strategic and long-term investment in innovation, infrastructure and skills.

[1] https://ifr.org/ifr-press-releases/news/record-2.7-million-robots-work-in-factories-around-the-globe

Overview

Over the coming years, there are challenges facing the pharmaceutical and biotechnology sector including how research into new therapies is conducted, as well as how these new therapies are then manufactured and then distributed. The healthcare sector is also seeing patients living longer and presenting with more complex health problems, which adds to the need for improved productivity as the sector moves towards the production of more personalised medicines.

As the complexity and variety of new drugs and therapies entering production increases, the pharmaceutical sector is looking for better ways to increase throughput, productivity and efficiency whilst reducing costs and overheads. Something that as a sector a wider use of robotics and automation could help to address.

Whilst the use of automation and robotics within drug development is not new and many agree that there are considerable benefits to be gained from the use of automation and robotics such as better use of existing resources through more round-the-clock working or faster analysis of data for example. There are still barriers for their more widespread deployment and challenges in their use within medicines manufacturing, as well as a hesitation to invest in robotic systems more widely.

Of the fifteen largest markets in 2020, the UK placed last in the number of installations of industrial robots[2]. By understanding the barriers and challenges that prevent more widespread deployment of automation, would provide opportunities for investment in innovative solutions to these. In turn this could help boost productivity and efficiency within medicines manufacturing and make the UK well placed to capitalise on the opportunities within this sector.

Is a process suitable for automation?

Within the field of robotics and automation, there is a general consensus that robotics will take over from humans in a range of broad areas - known as the 5 D's. These are defined as:

Dirty

Many tasks that are performed in manufacturing are inherently dirty. Using robots ensures high levels of sterility as well as ensuring that the human workforce are not exposed to potential health risks.

[2] https://ifr.org/ifr-press-releases/news/record-2.7-million-robots-work-in-factories-around-the-globe

Dangerous

A task where robots would be able to perform the same role as an employee, without the employee being put at risk. This could be for example handling caustic chemicals, or moving heavy tools or sharp equipment.

Dull

These tasks are repetitive and often tedious tasks which need to be performed consistently. Robotics lends itself well to this type of task, as it enables employees to focus on more interesting tasks.

Dear

A task where automation of this task results in saving money such as through a reduction in material costs or shortening of timelines or reducing delays in manufacturing.

Difficult

These are tasks which whilst possible to be performed by a human, are difficult or impossible to execute manually especially if consistency and reliability are required.

Many processes may lend themselves to automation, however these processes do not fall discreetly into one of these categories and so when considering whether a process should be automated, one should consider the 5 D's both individually or collectively.

The 6th D - Data

In addition to understanding whether a process should be automated, another aspect to consider is the data generated. It is important to understand the data that automation requires as an input (commands, parameters) and also the data that is produced through automation as well as how this data is generated, analysed, used and stored. Also important to consider is whether the data generated through automation of a process is used in real time, prospectively or retrospectively and what degree of access is required in the future.

Data therefore should be considered alongside the 5 D's of automation and not in isolation.As more steps within a process are automated, the data may play a large driver in the need for automation as more processes are automated and integrated together.

Background

Through a pre-workshop questionnaire, structured discussions and personal input have helped highlight a number of areas posing challenges to the community which straddle these six defined areas.

There was a mix of representations of people responding to the pre-workshop questionnaire, the majority of participants came from large business (>250 employees) or academic institutions, with the remainder being made up of small and medium businesses and industrial catapults.

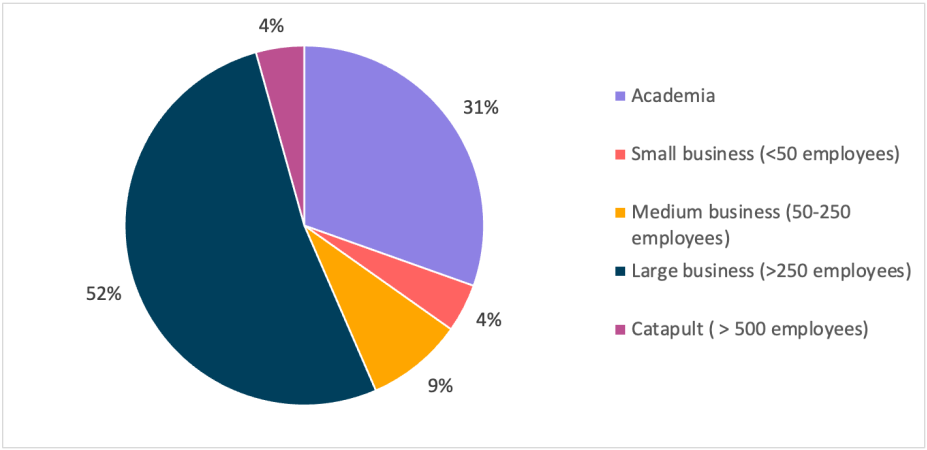

Figure 1: Proportion of respondents based on the size of their organisation

Generally these organisations focussed more on the research and development, process development and process scale-up, with lower levels of focus on pre-clinical production, clinical trial production, upstream and downstream processing as well as analytics. Only one organisation who completed the questionnaire had a business focus on fill-finish.

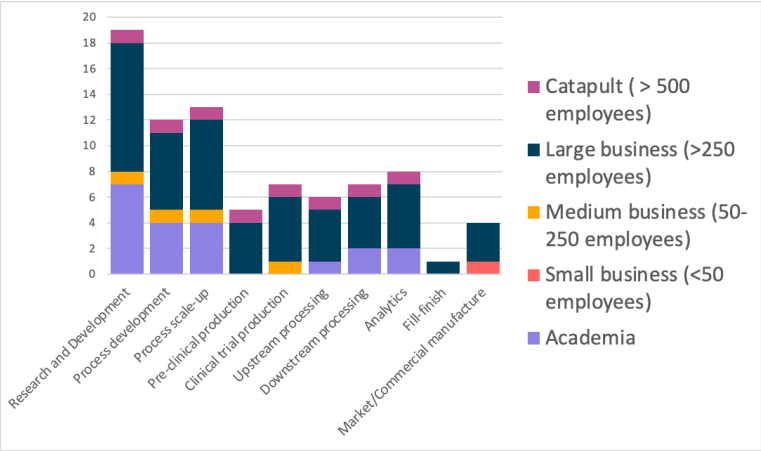

Figure 2: Stage of manufacturing that organisations work focuses on

Whilst most organisations said they had a digital framework in development, the majority of medium and large businesses, as well as academic institutions did not have this fully implemented.

Of respondents to the questionnaire, whilst most organisations said that automation was considered either occasionally, very frequently or always. Medium businesses stood out in the fact they reported very rarely considering automation when designing typical processes.

When asked whether automation was used within a typical process, most organisations reported only occasionally used automation, with both small and medium businesses reporting very rarely using it. Organisations that have gone some way to implementing automation were large businesses and academia.

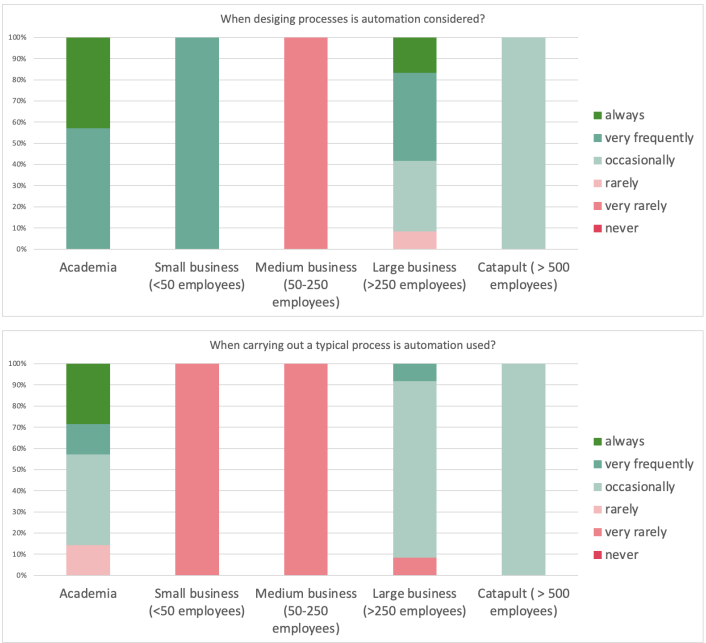

Figure 4: Breakdown by organisation type of frequency that automation is considered when designing processes (top panel) or carrying out typical processes (bottom panel).

When this question was broken down further, looking at the main drivers for automation within an organisation and which they had implemented. For many organisations there was a mismatch between what they thought was important and what they had implemented. Suggesting that for many organisations, identifying what processes they think should be automated was relatively straightforward, but finding and/or implementing a solution to this proved more difficult.

Figure 5: Breakdown by organisation type of drivers for implementation of automation (top panel) and the degree to which this has been completed to date (bottom panel).

In free text questions on the barriers to implementation and what business processes would need to change, the main trend in these answers was around cost of implementation, the skills

required to deploy and how to handle integration of new processes and infrastructure in a seamless manner.

These main barriers overlap in a number of different aspects to automation. It is therefore important to understand these responses in more detail. As such, an interactive workshop was performed to give organisations scope to contextualise these responses and provide more information on why these were seen as barriers to more widespread adoption of automation and to help identify gaps to help address this.

Dirty

Cleaning

One area identified during discussions which lacked suitable options for automation was cleaning (more specifically sterility), especially with respect to manufacturing suites involved in batch-based processes such as the production of advanced therapeutic medicinal products (ATMPs) such as patient-specific products or for change over cleaning within multipurpose production plants. This was an area where innovative systems could provide a significant benefit both to the quality of product produced, traceability data when it came to sterility and a reduction in losses which occur through contaminated products or carry-over between batches.

A real world patient benefit for this type of automation would be in the manufacture of chimeric antigen receptor T cell based therapies such as tisagenlecleucel and axicabtagene ciloleucel which requires T cells purified from the patients blood. Through a number of steps, these T cells are modified to encode a chimeric antigen receptor before being reinfused back into the patient. Release of the final product is reliant on sterility throughout, as well as having zero/minimal losses of the product along the way[3]. Due to the bespoke nature of this medicinal product and the severity of the patient's disease at this point, there is a high likelihood of not being able to go back to the patient for more starting material if manufacturing fails.

Automation of cleaning processes also is able to generate additional data which may be beneficial for manufacturers, technical staff and regulators. For example data generated by automating cleaning on the degree of contamination, areas which require more intensive cleaning, audit logging and how and when cleaning was performed.

Dangerous

Reducing operator exposure

[3] https://www.biopharmadive.com/news/novartis-hits-car-t-manufacturing-snag-as-kymriah-sales-disappoint/528202/

Another area identified which could benefit from the use of automation focussed on specific processes which require the use of hazardous chemicals, be that in routine use or when conducting routine cleaning or prior to maintenance. Whilst personal protective equipment and appropriate safety measures and training help reduce the risk to human operators, there still remains risks to the end user. Automation and robotics could minimise this risk further through reducing exposure to chemicals by the end user, especially for tasks which are repetitive and performed regularly by the same personnel.

Furthermore, as robots perform set tasks, they minimise the areas of surfaces within the laboratory that are exposed to compounds - reducing contamination of work spaces and helping protect individuals within the workplace. It would also allow contamination to be traceable back to a location more easily.

Repetitive manual handling tasks

Repetitive tasks, especially those involving fine motor control or limited range of movements present risks to users. This is especially a problem for organisations where team sizes are smaller as this means employees may be working on tasks with limited variety.

Testing a reagent using a sandwich Enzyme Linked Immunosorbent Assay (ELISA) requires the addition of four separate reagents, with three wash steps between each of them before a final development and quench step. In standard 96-well plate format, this constitutes 16 separate additions to each well of the plate for a total of 1536 additions per plate. To compound issues, if this has to be performed within a BSL-3 cabinet, employee movement is restricted further.

The above scenario highlights a broader opportunity for repetitive tasks conducted manually to be replaced by robotics and automation. This could improve ergonomics and avoid health issues such as Repetitive Strain Injuries for workers and also company losses due to sickness and ill health.

The above highlighted areas where significant costs and time delays can be incurred through incorrect procedures being followed, staff downtime or worse long lasting harm to staff members.

Hazardous environments

Within manufacturing, the scale-up of processes also adds inherent risks to the end user in terms of the volumes of reagents used and the nature of processes within some types of manufacturing. Here automation and especially robotics could prove to be beneficial by allowing physical separation of the end user from the hazard. It also provides opportunities to protect users with respect to routine manual handling and working within hazardous environments.

Dull

Critical to growth and development of an organisation is the ability to innovate and foster creativity within the workforce. This is especially important in an industry where speed and efficiency is of the essence. Automation presents an opportunity for organisations to use time and workspaces more efficiently whilst also offering opportunities to utilise the skilled workforce they already have in a more efficient and innovative way.

A standard UK workforce working a Monday-Friday, 9-5 working pattern works a total of 1740 hours a year per person. In comparison, robotics are theoretically capable of working 24 hours a day, 365 days a year or the equivalent of 8760 worker hours. A single step automated demonstrates a 500% increase in productivity, without factoring in the additional time that an employee is able to work on additional tasks.

A fully automated laboratory would ensure an efficient use of space, especially for organisations which lease workspace. Robotics would enable the development of 24 hour laboratories and the continuous manufacturing of products, with limited human involvement. This would be realised through an increase in productivity without significantly seeing an increase in the workforce. An added benefit to this would be that the environmental footprint of an organisation would drop as experiments were more reproducible and data more robust, resulting in less developmental waste helping organisations contribute to their goal of Net Zero.

Moving towards a fully automated process means that alongside being able to programme the system, other skill sets may be required by staff to be able to utilise the equipment to it's fullest potential This includes being able to programme the machine, as well as be able to troubleshoot and to perform routine maintenance. As technology progresses, the development of manufacturing equipment capable of self-reporting status before manufacturing runs start would be a real game changer when it comes to ensuring that maintenance issues do not impact production and manufacture and reduce overall running costs.

Dear

Hidden costs related to corporate knowledge

For many organisations, tacit knowledge instead of codified knowledge is an important and valuable part of any business, however it is only once a worker leaves an organisation, or the process must be transferred to another site, that the value of this is realised by the business - usually when it is too late. Automation allows data capture for more routine and/or mundane tasks in fine detail of instruction, outcome, measurement and error, without the additional work required to capture this being placed on the individual. This continuity in processes within and

across the organisation is of value and could serve to increase productivity and save costs to an organisation - for example when new staff are brought into the business, processes transferred to more cost effective facilities .

There are hidden costs to recruiting new staff members which go far beyond the initial salaried costs. During the first few months of work, a new staff member generally is performing at a lower level of productivity than somebody who has been at the organisation for a while. This means the cost of lost productivity falls on the employer[4]. Automation and the ability to capture routine but subtle data not normally captured by a new employee, is able to save the employer financially and in time.

Multi-step scale-up vs single-step scale up

Traditional process development approaches utilise multiple scale up demonstrations to proceed from the laboratory through to the plant for production. The use of automation and robotics from the beginning, offers an opportunity to design protocols that are repeatable and robust, enabling a process to be designed once and scaled up in a single step. To do this, requires an understanding of the technology, appropriate skills to code a scalable system and also a seamless automation journey between development and manufacturing. This requires integration and coordination across discovery, process development and manufacturing with full integration of hardware, software and interactions with data. Some of this technology is available but gaps need to be filled to connect all of these together into a seamless transition, especially as devices from different suppliers are often not fully interoperable . If this could be achieved, there would be considerable cost savings to organisations and a shorter time through development, reduced error etc. It would also ensure that research was repeatable, results were robust and regulators were able to sign off on new products.

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https://www.forbes.com/sites/johnhall/2019/05/09/the-cost-of-turnover-can-kill-your-business-and-make-things-less-fun

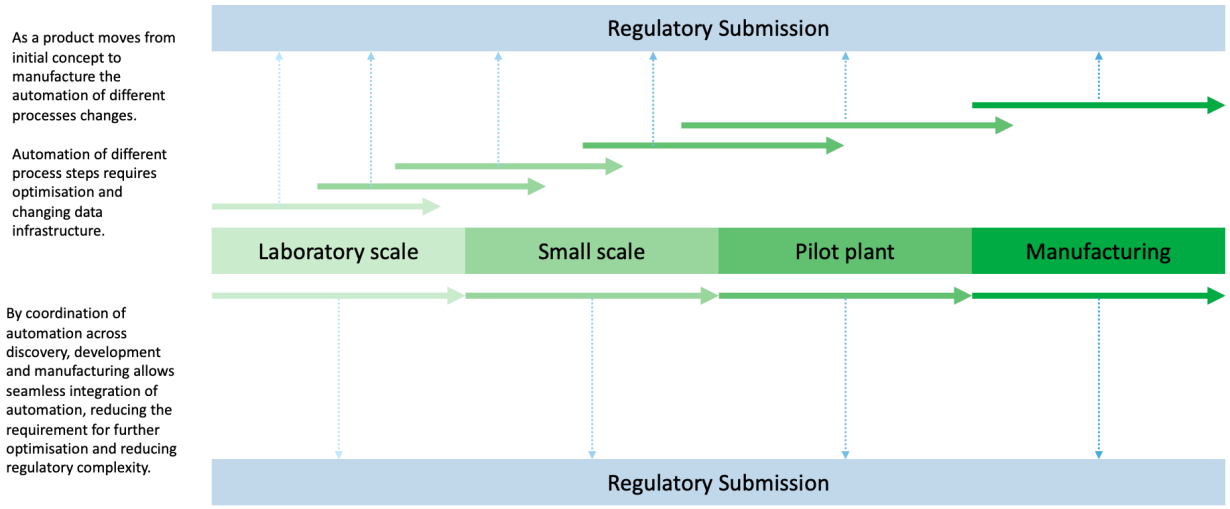

Figure 6: Inconsistent automation within scale-up leads to additional time spent designing automation, optimising process steps and capturing relevant information for regulatory submission. By coordinating the design of automation across discovery and scale-up reduces the requirements for optimisation and regulatory submission.

Difficult

Reproducibility

It should be noted that for many steps which involve humans there is often poor replication between scientists - both working in the same place or in different physical places. This poor replication is seen even when tasks follow the same standard operating procedures and the effect of this on data quality is unknown. One advantage therefore of using robotics and automation, is the potential for a higher degree of accuracy and precision - and therefore repeatability which automated systems allow. However many off the shelf robotics systems have been designed for classic industrial assembly tasks and not the fine control expected of a human technician. With proper maintenance and servicing, it is possible to maintain this accuracy and precision from experiment to experiment. Along with the additional information captured through the use of robotics and automation, it is also possible to identify deviations, for example identifying when a piece of robotics is moving out of tolerance.

Whilst the end goal of ensuring reproducibility and traceability are the biggest benefits to the deployment of greater automation, this also poses one of the biggest challenges.

Seamless integration

Firstly, there is the issue of integrating physical equipment with each other. Inherently, there is a tradeoff between having systems which are flexible and high throughput. Something that is not seen with the human workforce. As such, the more variations there are between each process, the harder it is to automate and the more likely an organisation is to rely on human intervention rather than automation.

The lack of a ‘one size fits all’ system, means that for many organisations the result is islands of automation i.e. individual steps within a process may lend themselves to automation, but these exist in isolation rather than being integrated from one end to the other. Modularity in system design and a key set of standards that equipment suppliers work to, common in other industries (automotive, semiconductor) with mutually agreed interface points offers the possibility of enhanced levels of flexibility. To address this fully, the range of technologies available must be developed in parallel and individual technologies need to be able to handle multiple different scenarios rather than an individual isolated process step. This is even more important when working across different geographic areas or sites.

Figure 7: Where there is a lack of flexibility within automation systems, islands exist within processes (1-4). Where technologies are able to handle different scenarios rather than individual isolated steps, integration of automation is seamless.

User interfaces

For automation to be more widespread, the user interface must be easy to navigate and programme. Currently many products on the market are generally built on a bespoke interface for a particular activity, which requires the workforce to learn how to ‘drive’ the system, how it was built and where the boundaries of its capabilities lie. In addition to that, different systems are coded in different languages and handle data in different ways, meaning there is a general lack of interoperability between different systems, regardless of supplier. This can also be true with integration of legacy systems with newer technologies or capabilities.

Set-up time

Compounding this issue is the fact that many systems are not easily able to switch between different methods, requiring time to set-up, additional input coding and calibration. This means that systems are not easy to change on the fly - unlike a staff member who is able to move from one experiment or process to another with relatively little downtime between them.

Sensors

For a system to be properly automated, requires the development of appropriate sensors which are able to interface with the robotic systems. This highlights further challenges - do we need more sensors within a pipeline to provide timely, meaningful and robust information? Where do these sensors go? What are we using the data for? How will the data be communicated and where will it be stored, managed, maintained?

For many processes, the technology does not currently exist - for example in RNA manufacturing, the ability to monitor processes continuously is not available at the current moment in time. This means that even with the addition of automation and robotics within this pipeline, there still exists discontinuous analytical steps which act as bottlenecks within this process

Analytics

Furthermore, one must not forget the additional component that is required in parallel with automation and the use of sensors - analytic, potentially very rich in information (vision, spectroscopy). The lack of interoperability for many systems with analytical tools means that whilst the process itself may be automated, a lot of the data analysis still has to be conducted offline. This data analysis happens in a discontinuous manner rather than continuously and as such relies heavily on having a skilled workforce who understands the data that is being generated and is able to identify deviations from what is expected.

Data

When a process step is automated, there is a considerable amount of data generated. This means that for the successful deployment of robotics and automation the data and IT infrastructure require upgrading to handle the volume of data that is coming through, especially if this is to be analysed in real time rather than offline.

Data capture

The scope of data capture is not limited to the experimental data that is generated, but also from meta-data that is captured on the fly from the use of robotic systems (data about the data, date/time, temperature, batch number, calibration, context etc.)

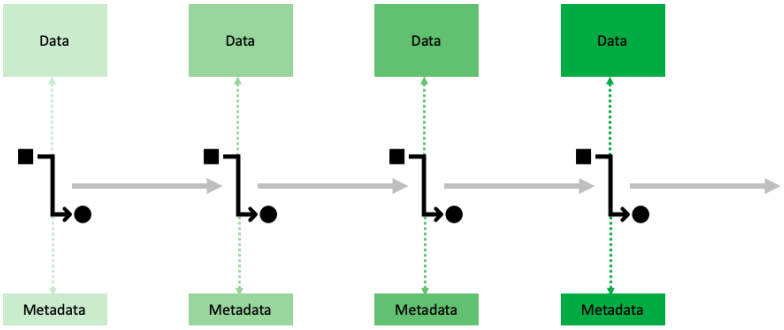

Figure 8: Process steps and sensors generate both data and metadata as outputs. Correct use, storage and analysis of this provides an opportunity to improve individual process steps.

Examples of metadata which could be captured by robotic systems include stirring speed, atmospheric pressure, probe temperature, salinity, pH, user, run time to name a few. This needs to be captured in a machine readable and in a standardised, semantically labelled and searchable format which integrates into electronic laboratory notebooks, as well as potentially powerful machine learning/artificial intelligence systems with different expectation of the data than a human operator.

Through capturing this metadata and utilising it instead of just storing it is key to being able to automate processes. However to do this, the metadata must be meaningful, machine readable and usable as the base for automation. Metadata also needs to be structured in a way that enables access and searchability both for use as a resource for the future, but also from a technical standpoint for use with regulatory authorities.

Negative results

Another area where automation is important, is that robotics are agnostic about the end result. Scientists may not capture data from failed experiments e.g. through not writing up the experiment or capturing lessons learned which hinders learning for subsequent development activities for example modelling or identifying failures within a process. This is proving critical for machine learning systems which may otherwise overgeneralise and malfunction. Through addressing incomplete data capture through the deployment of automation can in due course increase process understanding and create positive feedback loops.

Data analysis

Due to the volume of data generated and the complexity of this data - especially with the addition of metadata, turnaround time has to be rapid and functioning around the clock. For this to work requires data to be processed and used in real-time for decision making, whilst also capturing this information in a manner which allows retrospective analysis of the decisions computationally made.

To offer a significant advance all data generated and captured has to be both machine-readable and machine-actionable i.e. enabling a degree of machine autonomy in decision-making, supported where appropriate with human input. Furthermore there needs to be a consistent standard in the way that data is obtained, processed and stored to ensure that data can be used and decisions made based on that data by either operator or other systems. This is even more important when systems are built using parts from multiple vendors.

Visualisation is also important for this human input, so ensuring that systems have visual readouts such as data dashboards is vital for a fully integrated and automated system to work efficiently. This should provide enough information for the end user to be able to assess processes, without overwhelming them with additional data.

Another important question to consider is how exactly is the data analysed and what is done with the data once it has been analysed? Is this data analysis done on the fly through the use of machine learning/artificial intelligence or is this still done by human intervention? How is the decision made and what safety measures are in place to ensure that decisions made are properly documented and acted on?

Traceability

For data to be useful, it must be traceable on a multitude of levels. This includes a specific instrument or run right down to a specific batch of reagent or well location on an assay plate. This traceability must be able to be integrated with an existing Laboratory Information Management System (LIMS), without being arduous to the end user.

Useability

Whilst with any process, more data is useful. The question arises, is the data generated useful? How is this data and the knowledge about the process it pertains to used to understand and improve the process? Whether this happens online or offline, it requires a fundamental understanding of the process as a whole, as well as what was performed at that step within the process. The balance between ‘big data’ and ‘right data’ needs to be carefully considered, especially given the cost involved with storing data which is not appropriate or usable.

Information security

Underpinning digital automation is information security. As more systems are automated and robotics are more widely deployed, this creates additional weaknesses within IT infrastructure. Especially where systems are provided by multiple vendors or are coded in house, there is a new level of security needed to ensure that system security is maintained and data is housed in a safe and secure environment, with appropriate precautions and access requirements met.

This requires not only the individual end users to understand what a system does and how it interfaces with existing security and IT systems, but also for a more top-down approach with in-house IT teams.

Furthermore, as data of this type holds competitive advantages, an understanding of where data is stored, in a secure format and in a manner which enables cyber security breaches to be identified swiftly and acted upon.

Information security with regard to data transmission is also important, especially for datasets hosted within the cloud. Advanced robotics which are not physically segregated from the human workforce also poses safety risks to the user if cyber security is not adequate as control of these systems may occur remotely and not through the physical end user.

Skills

To fully realise the successes that the implementation of automation and robotics can bring to the medicines manufacturing sector alongside infrastructure will require additional investment in skills and training.

The implementation of automation and robotics will require more interdisciplinary working than the sector is traditionally used to. Whilst there will still be a need for human input - with humans involved in operating and programming machines. There is also a requirement for training individuals who understand both the world of science and the world of automation and robotics. This digitally literate workforce can come from both sides - people who are trained as scientists first and foremost, but who are trained in the use of robotics and automation and also individuals who come from a computational background, but are reskilled in science and technology.

As a sector to address this, there will also need to be a rethink in remuneration of these individuals to attract individuals to the sector as well as maintain the existing workforce once reskilled.

Furthermore, there is a requirement for a more digitally literate workforce outside of the staff working ‘at the coal face’. A better understanding of the digital backbone, data handling, cyber security and additional aspects that an organisation is faced with when greater levels of automation are deployed is required to fully realise the benefits that automation can have to a business.

Training

It is also important to fully understand the scope of automation and the interplay between different pieces of software and hardware to be able to fully grasp training requirements. Having a clearer vision and understanding of the language that equipment is coded in, the data that is

generated and the data and systems architecture, provides a steer and direction for additional training needs for staff being reskilled to work in a digitised manufacturing environment or for identifying new talent to be brought into the organisation.

Regulatory

A barrier to the more widespread adoption of automation within process development is the final regulatory steps required prior to being able to release a product to the market or end user. Whilst the sector has seen step changes in the use of automation, both in the scope of equipment and software which is available for purchase, there is a lag between more widespread adoption of this technology and regulatory requirements - with the latter needing to adapt and adopt processes to enable compliance.

As with the adoption of new technologies, there is a tipping point which has yet to be reached whereby enough organisations adopt a particular technology for regulators to have approval processes in place to demonstrate compliance. When considering the implementation of automation by an organisation, there are many suppliers providing software/hardware to satisfy requirements. However, these disparate options mean that regulatory bodies are unable to have a single approach - unlike when processes are conducted by a standard workforce performing known tasks. This demonstrated regulatory compliance serves as a major barrier to adoption because understanding which technology to deploy is difficult without knowing what regulatory bodies require. Yet regulatory bodies themselves, require advice/data to make these decisions.

Regulatory flexibility

Working within the regulated environment adds additional difficulties. To transfer existing methods to automated platforms may require additional regulatory submissions. Further regulatory amendments may also be required if changes are required due to software or hardware updates, changing platforms. This all adds complexity to the regulatory frameworks and approvals processes associated with regulatory submissions.

Equipment validation

Furthermore, to add additional complexity to this regulatory aspect for automation is that the suppliers of equipment are not always the same people who work within the regulatory field. As such, the method by which automation is coded is not always standardised to fit with regulatory requirements. Also raising the question of who is responsible for ensuring that the coding of software is appropriate for the process and validation activities required to get regulatory approval? Where does the cost for this lie?

Business need

Finally when it comes to the more widespread adoption of automation and robotics, one of the biggest barriers is from within an organisation itself. Building a business case to understand what to automate and the impact that automation will have on the workforce and organisation as a whole is a large undertaking with many unknowns. Understanding what to invest in and the impact decisions make is a challenge that all organisations face.

Choosing appropriate solutions

Organisations also need to understand which solution best fits not just their requirements now, but also their requirements in the future. This involves a degree of horizon scanning, to understand the direction of travel of the sector. Also having a workforce who already understand the detail required to properly design and scope out an integrated system is difficult, especially when they may not have a full appreciation of what the capabilities of systems are and what systems are available and at what cost.

In addition, as detailed earlier - key to all of this is fully appreciating the importance of cybersecurity and how systems connect together seamlessly without exposing the business to unnecessary weaknesses and vulnerabilities which could be exploited by external threats.

Suitability of laboratory space

Important to consider is the suitability of laboratory space. For many organisations, the workspace has been designed with a human workforce in mind that isn't easily adaptable to deploy robotic systems more widely without sacrificing space elsewhere or without requiring major changes to laboratory space - which come at a cost to the organisation both financially and in down time. Again modularity, and also accessibility guidelines may play a useful role here.

Post-workshop findings

Of respondents to the post-workshop survey, 100% of people who attended the workshop and completed the questionnaire found that the session was useful. With the general consensus of attendees having a positive view of both the breakout sessions.

Many people who attended the workshop highlighted that the breadth of the topic was large and that at times it felt as if the workshop was only 'scratching the surface' of the many aspects that robotics and automation had and how these impacted the sector. Respondents felt that further refinement of the scope of activity should be conducted, especially to understand the interplay between robotics and automation - which whilst there is interplay between them, should also be considered as separate topics in their own right.

Respondents were keen to expand more on the topics identified and felt that the use of case studies where this had been successfully deployed in other industries would be helpful to generate sector or business cases for deployment. However, there was a concern that with regard to funding there should be a clear distinction between any UK-wide pre-competitive activities and funding to specifically address areas of unmet need within an individual organisation.

Data including data capture, analysis and storage, as well as the integration of data and systems was a strong topic for future ideas as this forms the foundation that can then be built upon with any solutions which exist already or which are to be formulated in the future. Interest was expressed for case studies, workshops and visits, whilst to a lesser extent signposting to facilities and capabilities across the UK.

Finally from the post-workshop questionnaire it was highlighted that upskilling middle and senior level managers in understanding the requirements of automation and robotics, identifying benefits, pitfalls and workforce impact should also be considered as a way to help remove barriers to implementation within the sector here in the UK.

Top focus areas and next steps

The top three focus areas identified from this workshop and questionnaires were:

- Integration and interoperability
- Data
- Skills

To build on this, a follow-up workshop has been arranged at the University of Sheffield Advanced Manufacturing Research Centre (AMRC) on the 30th March 2022. The aim of this workshop is to focus on how the industry can move from a manufacturing set-up which uses minimal software or automation with a strong focus on process steps being conducted by staff and move towards a highly integrated system where physical and virtual experiments are conducted in a single workflow.

This workshop will feed into a wider piece of work combining stakeholder engagement events, questionnaires, case studies and other tools to understand where innovation can play a part in deploying automation and robotics more effectively across the Medicines Manufacturing sector.