Does Industry 4.0 pose a challenge for the SME Machine builder? A case study and reflection of readiness for a UK SME.

Mark Jones, Leszek Zarzycki and Gavin Murray

TQC Ltd, Nottingham UK, www.tqc.co.uk

Abstract. TQC is a special purpose machinery builder. We became aware of the Industry 4.0 concepts and decided to investigate whether we were already prepared for what has been termed the fourth industrial revolution, or whether there were new concepts and practices that our company should adopt.

This paper shows the process through which we evaluated the aspects related to the Industry 4.0 definitions. We dissected the various core concepts and then expanded the process to cover the nine pillars on which Industry 4.0 is built. We assessed ourselves against each significant element to see if we understood the concepts and requirements. We asked if these aspects were relevant to our business, we assessed whether our experience and actions to date covered the core of each element. We also looked at the challenges Industry 4.0 poses for the future of our business.

This paper is a review of the process and it presents our findings.

Keywords: Industry 4.0, SME, Case Study.

1 Introduction

The continuing drive for improvements in industrial productivity combined with the technological advances in IT systems are driving manufacturing industries through what has been termed the fourth stage of the industrial revolution known as Industry 4.0. This paper reviews the technological advancement from a personal view of a UK SME, TQC Ltd, matching personal and company experience against the requirements of Industry 4.0 and asking "are we ready?"

It is acknowledged that since TQC Ltd supplies special purpose manufacturing and test machinery into large volume producers, our perspective on Industry 4.0 is influenced by the demands of our client base. It is our client base that drives TQC into addressing the challenges of Industry 4.0 as an early adopter within the SME sector.

TQC's understanding of Industry 4.0 was first challenged by a request to give an SME perspective to a local workshop on the subject early in 2017. This meant that we had to research the definitions and the concepts behind Industry 4.0. We knew of the term but had no detailed understanding of the depth to which this terminology had been developed; this is perhaps a telling observation. As we researched the subject, it became apparent that although we were not familiar with the definitions, many elements of Industry 4.0 had long since been adopted by our clients, and our machines had for many years incorporated some of the aspects that characterise Industry 4.0.

TQC therefore embarked upon an exercise to fully understand Industry 4.0. This started by: -

- researching the definition of Industry 4.0, this led us to
- a review of the *nine pillars* of Industry 4.0, then
- assessing the challenges to implementation of Industry 4.0 and finally
- a review of the *6 C*s related to big data

2 Assessment of the definition of Industry 4.0

How has Industry 4.0 been defined? As a non-academic organisation the first port of call is Wikipedia, which asserts "Industry 4.0 is a name given to the current trend of increasing automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the Internet of things, cloud computing and cognitive computing" As TQC has been a beneficiary of several funded research projects with Nottingham University and others in topics such as Evolvable Systems and Smart Factories, this definition of Industry 4.0 had a familiar resonance.

Industry 4.0 is portrayed as the beginning of the fourth industrial revolution.

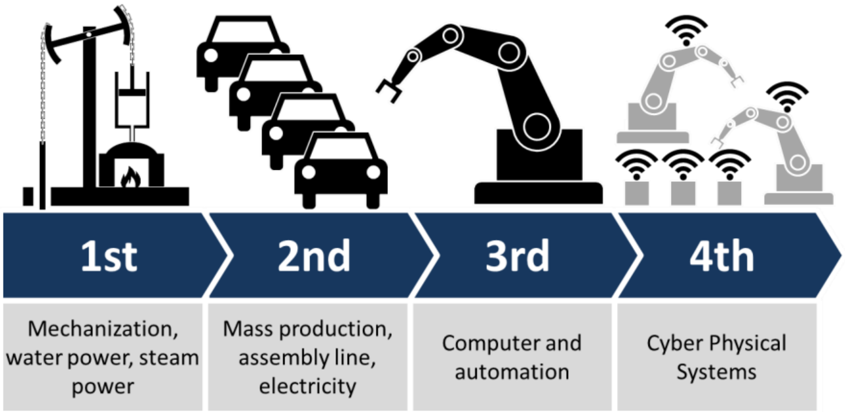

Fig. 1. The path to Industry 4.0 (Roser, 2017)

Deeper investigation uncovered that there seems to be no agreed definition of the term Industrie 4.0 first coined in Germany. The origins of Industry 4.0, alternative definitions and a critique of the Wikipedia definition as "*What Industry 4.0 is not*" can be found in i-Scoop. (i-SCOOP, 2016) (https://www.i-scoop.eu/industry-4-0/). Nevertheless, the definitions concur that Industry 4.0 is the convergence of many of the technologies underpinning the smart factory.

There appear to be four basic design principles in Industry 4.0. (Hermann, Pentek, & Otto, 2016) These principles support the identification and implementation of Industry 4.0 scenarios. These can be listed as follows:

- Interoperability: machines, devices, sensors and people that connect and communicate with one another.
- Information transparency: the systems create a virtual copy of the physical world through sensor data in order to contextualize information.
- Technical assistance: both the ability of the systems to support humans in making decisions and solving problems *and* the ability to assist humans with tasks that are too difficult or unsafe for humans
- Decentralized decisions: the ability of cyber-physical systems to make simple decisions on their own and become as autonomous as possible.

The above has been further divided into the Nine Pillars of Technological Advancement. (Rüßmann, et al., 2015). TQC used this definition to further evaluate the differing aspects of Industry 4.0 in detail.

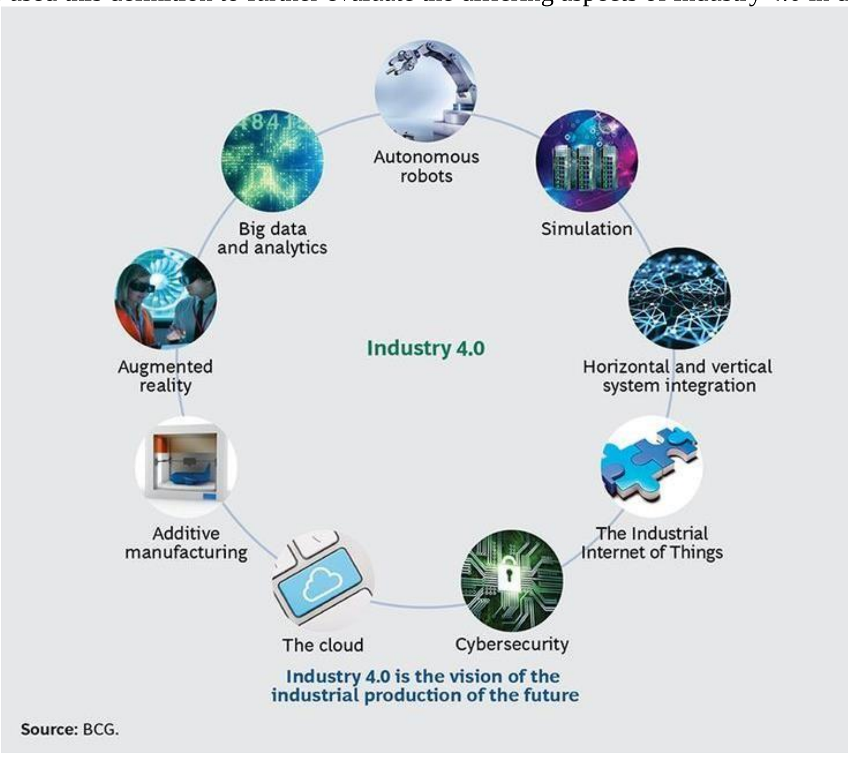

Fig. 2. The nine pillars of Industry 4.0 (Rüßmann, et al., 2015)

3 Assessment of TQC Capability against the Nine Pillars

3.1 Big Data & Analytics.

The advancement in control systems in recent years has driven a number of key aspects for machine control and data acquisition. The relative low cost of large amounts of memory is allowing much more production information to be stored. This is further enhanced by the ever-increasing speed of processors reducing the control scan time and therefore allowing high transient rate signals to be stored and processed. So, the ability to create big data and then process it has driven the need for better analytical tools for data mining and to produce meaningful decision-making capabilities.

An example of a recent project engineered by TQC is a high-speed machine to perform a high-quality leak test on a medical device. The device is plastic, the technique for leak testing is helium mass spectrometry and the transient nature of the signal received by the instrument recorded the permeation of the plastic to helium. The challenge was to differentiate between permeation of helium and small level of leakage.

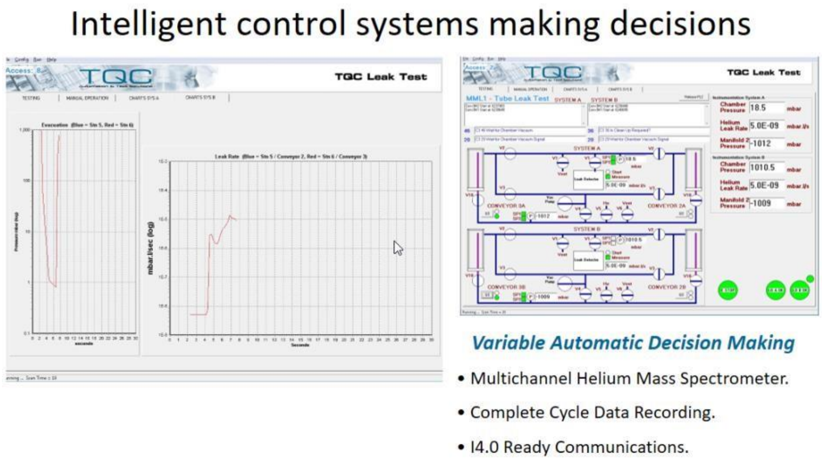

Fig. 3. Pages showing the high speed transient and the combination of machine status

In order to build in the decision making into their control system, TQC had to collect many sets of test data and from them identify the characteristics for permeation and leak. The data analysis tools used were spreadsheets, graphs and brains. Is this Big Data? Probably not. But it does involve the collection of a volume of data in real time leading to its rapid analysis at the machine level and the autonomous decision process described above.

Many in manufacturing may believe that they have always been collecting and analysing process and production data, and that Big Data is a marketing buzz word. (Littlefield, 2015) However, this is a limited view in contrast with the concept that Big Data requires advanced analytical methods to gain insights from structured and unstructured data sets garnered from a variety of sources, such as internal, customer, supplier and machine data. (Littlefield, 2015)

If the published benefits of Big Data are to be believed then, there are clearly opportunities for TQC to use data analytics to support maintenance and after-sales services, and to uncover insights into its own business. The former is dependent, however, on having the agreement of the client to process their data. Additionally, TQC would need in-house training on data analytics in order to understand its complexity and potential benefits to the company.

A further assessment of TQC with regard to big data is given in section 5.

3.2 Autonomous Robots

There is no doubt that industry is adopting the use of more robotics in automated systems. The cost of sophisticated robots has decreased and the appearance of newly packaged low-cost motive elements known as “electric cylinders” that work like pneumatic cylinders but which are servo position programmable means that simple robotic elements are now commonplace. The integration of these technology modules is allowing more repeatable consistent control of processes, systems that do not tire and providing a lower cost compared to the employment of an operative. More complex systems are also possible where robots can co-operate with other robots and safely cooperate with humans.

Approximately 10 years ago, TQC supplied a high-speed system whereby two cooperating robots shared a gluing station and a UV curing station for the production of stay up stockings. Both robots had to use common areas for the gluing and curing, with operators positioning the highly flexible and dimensionally inconsistent parts “the stockings” onto mandrels, where the operator ensured that the line where the glue was placed was aligned. Each robot knew where the other was and would not enter a space occupied by the other robot.

Fig. 4. Image of co-operating robot system for processing stockings

3.3 Simulation

3D CAD has been used for many years for the production of drawings and assemblies, TQC has for the past 8 years been using this for the production of our machine systems. Active mechanisms can be simulated within such packages and properties such as mass, tolerances and inertia, estimated before manufacture of parts. Simulation of motion control components like servo systems is now common place to aid system design and component selection.

TQC have also been involved in several EU Part Funded projects notably E-Race, EUPASS and PRIME all of which were focused on improving the production process through the use requirements capture, flexible and reconfigurable architecture and the development of new technology modules.

As a direct result of the EUPASS project, TQC were able to produce a robot manipulation system capable of manufacturing Wills Rings. Wills Rings are metal O-Rings for static face-sealing applications that give reliable performance over a large temperature range for gases and liquids. The system was capable of manufacturing a wide range of diameters and configuring itself to a different size at the push of a button, based on an operator recipe selection.

In addition, the images from the project below show an aerospace application engineered by TQC whereby the 3D CAD drawings were used to lead the operator through the standard operating procedure (SOP).

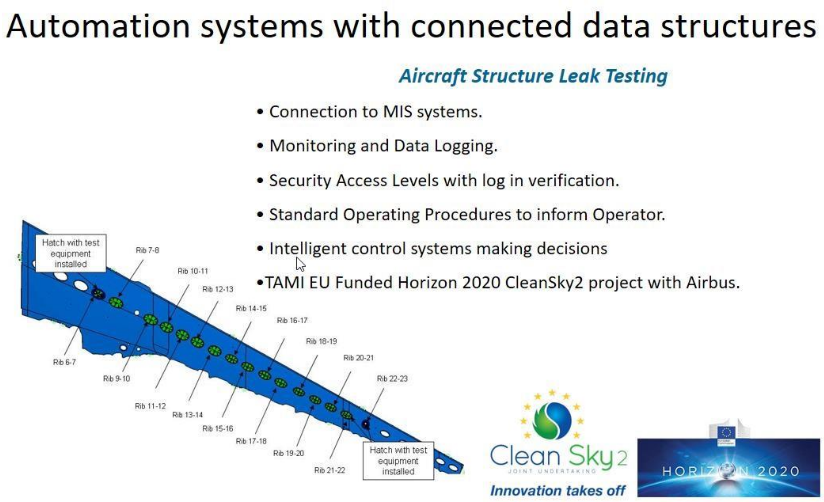

Fig. 5. Automation system with connected data structures

3.4 Horizontal and vertical IT system integration

Companies, departments, functions, and capabilities will become much more cohesive, as cross-company, universal data-integration networks evolve and enable truly automated value chains.

In recent years, the need to transfer data to the machine to configure the assembly process, and from the machine to convey checks and test parameters that define that the assembly process was correct, plus additional information about the exact measurements taken to address tolerance drift and tool wear has increased. Initially, TQC were just asked to time and date stamp correct and incorrect parts and assemblies, this was easily achieved by having a simple structure for the storage and backup of the data, usually .csv files. More recently, TQC has been asked to engineer machines that communicate directly with SQL type databases on our client's systems, storing both measurements and machine vision images.

It is recognized that these are only small steps in horizontal systems integration. Measures leading towards vertical integration are perhaps exemplified in section 3.7(The Cloud).

3.5 The Industrial Internet of Things

The internet has developed into a system where local and remote connectivity is common. There are now many technology modules for automated assembly that are internet ready. Most of the recent machine systems currently engineered by TQC have multichannel Ethernet hubs with the configuration, interrogation and communication of data being bi-directional.

As an example, TQC as an expert in Leak Testing has developed, with the aid of a UK Innovate Smart Grant, a new leak test instrument that is truly an Internet of Things device. The unit shown below has the ability to connect intermittently for dynamic configuration or be permanently connected for real time transfer of leak test parameters and results. Additionally, the unit has a simple communication protocol that can be used with fixture controllers that clamp, seal and then release an item that is being tested. This has been an interesting exercise and was completed before we knew what Industry 4.0 meant. The unit is Industry 4.0 ready.

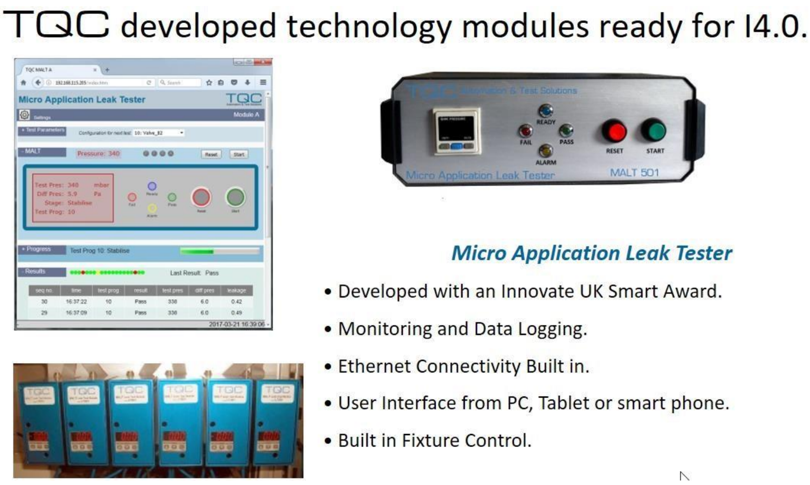

Fig. 6. TQC leak tester module ready for Industry 4.0

3.6 Cybersecurity

Cyber security includes controlling physical access to the hardware, as well as protecting against harm that may come via network access, data and code injection.

Recent projects completed by TQC, specifically in the Aerospace, Medical device, Nuclear and Military sectors, have requested double PC firewalls and the provision of malware programs to protect the integrity of the control systems for automation from unwanted access and attack.

Indeed, one of our clients had a malware attack from the Wannacry virus. It stopped all production because of poor security by the underlying operating system. Of course, the integration of machines into a company's data network requires careful planning of the infrastructure. Segregation of machine networks and IT networks is common place and advantageous in controlling access and security of machine systems.

3.7 The Cloud

To date, TQC has not been asked to use Cloud structures for production equipment. However, for some clients we are integrating high level PLC controllers that have embedded software for storage of data in SQL type databases. TQC knows that it is just a matter of time when this will become common place and extend to Cloud storage and associated functionality.

To prepare ourselves for Cloud based data structures and to improve our own Manufacturing Execution Systems (MES), TQC has embarked on transferring our 1980s DOS based internal management information systems onto Cloud based data structures. The project is part funded by an EU RDF Grant Funded Project within the Nottingham/Derby Local Enterprise Partnership as part of the regional Digital Growth Programme. The migration of our existing resource recording system to the Cloud has already taken place, the migration of the bill of materials system to an extension of the same Cloud database is expected to be completed at the end of November 2017.

Our plans for our new MES system do not finish with the migration of the historical data. Once we have both data base systems combined we are proposing to also enter the project budget information and then use "S" curve (Sigmoid based function) prediction as the project is being engineered. Our ultimate goals are "Project on a Page" and "Company on a Page" reports that will track the projects in real-time as they are progressing.

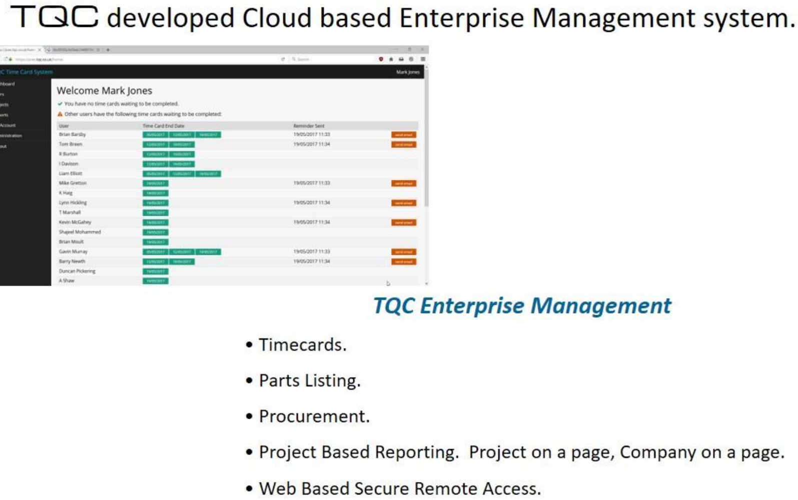

Fig. 7. TQC's Cloud based Enterprise Management System

Having completed the resource recording system, TQC is already reaping the benefits of real-time tracking and review of the labour aspects of the projects.

3.8 Additive Manufacturing.

As opposed to traditional techniques where material is removed from stock, the new technologies in additive manufacturing are providing some benefits to the SME machine builder mainly in the field of fixturing for complex shapes.

TQC has limited experience in this area but has used these techniques to seal complex aero-engine castings, military rockets and automotive parts. We are not currently at the point whereby we have our own 3D printing system but are currently using capabilities of our suppliers and familiarising ourselves with the techniques and possibilities that additive manufacturing provides.

Fig. 8. An example of 3D printed parts used as fixture nests in a TQC machine

3.9 Augmented reality.

This is the one of the nine pillars that we have yet to use in a commercial assembly environment. This is probably because TQC predominantly supplies test and assembly systems into volume producers. We see more of a use for this technology in low volume technically complex products both for assembly and for maintenance purposes. Nevertheless, augmented reality toolkits are readily available and TQC envisages the day when a client requests an AR application to complement machine maintenance and operation.

3.10 Summary of 9 Pillars Assessment

According to Freudenberg IT (2014) (in Sommer, 2015) "The values concerning the important foundation pillars of Industry 4.0 like for example machine data collection, plant data collection, the connection of MES (= Manufacturing Execution System) to commercial systems as well as automatic production processes have all increased significantly" TQC concurs with this statement, we are finding an increased number of requests to use more expensive and sophisticated control systems capable of processing the large amounts of data within the machine and to produce the data for MES systems.

4 The challenges in implementation of Industry 4.0

The challenges in implementation of Industry 4.0 are already well documented according to Lavanya B et al.:

1. "IT security issues, which are greatly aggravated by the inherent need to open up those previously closed production shops
2. Reliability and stability needed for critical machine-to-machine communication (M2M), including very short and stable latency times
3. Need to maintain the integrity of production processes
4. Need to avoid any IT snags, as those would cause expensive production outages
5. Need to protect industrial know how (contained also in the control files for the industrial automation gear)
6. Lack of adequate skill-sets to expedite the march towards fourth industrial revolution
7. Threat of redundancy of the corporate IT department
8. General reluctance to change by stakeholders
9. Loss of many jobs to automatic processes and IT-controlled processes, especially for lower educated parts of society" (Lavanya, Shylaja, & Santhosh, 2017)

TQC have come across all these issues as we progress to produce machines currently being specified by our clients with various aspects of Industry 4.0 embedded into the systems.

The first two elements (1-2) listed above are developing as technology follows the requirements set by industrial standards and obliges an organization to follow continuous review and updating. The following three elements (3-5) mostly relate to cybersecurity which one should have under continuous review and reassessment. It requires that the automation system provider ensures that the relevant protection is installed, monitored, reviewed and updated these elements should be covered.

The lack of adequate skill sets and the reluctance to change are continuous challenges for the SME; it is important to nurture an environment that is open to new ideas, new technology and to change. The last element (9) is something to which one should be sympathetic and ensure that there is a corporate responsibility to continuous education, training and development.

5 An assessment related to Big Data

How big is big data? Clearly the data TQC is being asked to collect is more voluminous than in the past. The lowering cost of memory and increased transfer speed is making the collection of large amounts of data from quantitative sensor systems possible and so we collect more because we can! But does the quantity of data that machine system builders are likely to collect need to be addressed as big data? Some sources are indicating that big data is above 1TB. In most of the machines and production lines we are asked to build it would take over 50 years for the system to collect that much data; so, are big data techniques really relevant to the machine or system builder?

TQC's view is that knowledge of big data techniques including data mining, aggregation and analysis will become more important in the future and many of the techniques developed for handling very big data will be relevant for smaller data quantities. We must also have an appreciation of these techniques to be able to present machine data in portable formats, probably incorporating semantic information. Whereas in the past a simple table/matrix structure with column and row headers were acceptable, SQL type data structures may require for each cell/field of data to also have a tag associated with it to allow a more free-flowing data structure and one that can be data mined more easily. TQC are currently looking at projects where this type of data storage will be used by us for the first time.

5.1 The 6Cs of data analytics

According to Lee et al. (Lee, Bagheri, & Kao, 2015) big data analytics consists of 6Cs in the integrated Industry 4.0 and cyber physical systems environment. TQC's assessment against each of these criteria is as follows:

1. **Connection (sensor and networks).** TQC's capability to engineer complex machine systems with a full set of connections to sensors through direct digital or analogue I/O or bus systems to either PC or PLC architectures at machine level is well developed having over 30 years' experience of instrumentation and data acquisition. The connection of PC or PLC systems through either Ethernet, WIFI or serial communications platforms has been performed as the technology has become available.
2. **Cloud (computing and data on demand).** TQC's exposure to Cloud based systems is a recent feature; it is certain that Cloud based technology will become an important aspect of our machine design in the future. To prepare ourselves for Cloud based systems, TQC has embarked on its own 'little' Big Data project by transferring our management information systems to the Cloud and to then attempt to extrapolate this data to improve the efficiency with which we are able to engineer special machines.
3. **Cyber (model & memory).** Increasingly, we are being asked to engineer extensive interconnected systems and provide a remote model of the system for production monitoring, servicing or maintenance. Complex models of aircraft wings have been recently adapted for use in guiding operators to do complex tasks. Sophisticated models of complete production lines have been duplicated to provide real-time data for use in monitoring and production planning. Web enabled camera systems have also been used on installed production systems for open monitoring of the status of production systems.
4. **Content/context (meaning and correlation).** It is clear that we must not provide Industry 4.0 systems just because we can, there needs to be a match between the commercial need and the provision of the tailored systems capable of exploiting the new technologies and understanding of what can be achieved to improve efficiency and profitability.
5. **Community (sharing & collaboration).** Open sharing has been arranged by negotiation to allow access to machine status and video streams into large multi-image screens showing working production. Some clients are more open than others, and some departments within companies are more open than others. Threats to the existing status quo are perceived and need careful negotiation.
6. **Customization (personalization and value).** Many of the systems that the special purpose manufacturer is asked to supply whereby an order for a specific realisation of a product, for example "Mr. Smith's right-hand drive sports car, red with parking sensors", is sent to the manufacturing/assembly machine for scheduling into the sequence of assembly on the car line has been in existence for over 15 years. There has also been a need within the pharmaceutical and medical device industry under the direction of the US FDA for traceability of the circumstances of manufacture for individual and batch items.

According to Rüßmann (2015) "Analytics based on large data sets have emerged only recently in the manufacturing world, where it optimizes production quality, saves energy, and improves equipment service. In an Industry 4.0 context, the collection and comprehensive evaluation of data from many different sources—production equipment and systems as well as enterprise- and customer-management systems—will become standard to support real-time decision making." (Rüßmann, et al., 2015) TQC believes that providing the full range of capabilities to all machine systems will not be necessary; having the capability to pick and mix to provide the optimum set of enhancements is the key to commercial success.

6 The pressures on manufacturing system suppliers and specifiers.

As the technology in system components increases and as further possibilities for data streams develop, the system supplier will need to keep pace with the demands that these developments place on data management within machine, system, production line and its connection to the wider data environment.

This will require significant investment in IT resources; hardware, software and the software engineers who will be responsible for implementing systems that have Industry 4.0 requirements. TQC are already seeing many requests for increased data storage, the inclusion of video and screen information saved as images, and the requests for SQL type data structures. Despite the request for the additional data to be stored, when our clients are asked “what are you going to do with the data?” the response is often unclear.

There is a need for the specifiers of data structures within our client companies to also understand where their data requirements currently stand and plan forward for potential requirements in the future. The most cost-effective way to implement large data capture is to build the machine with this in place at the start. It is possible to retrofit the infrastructure but sometimes this requires a complete rebuild of the control system. Machines that we supply now will most probably be in production for many years to come, so when considering a new system or machine an in-depth assessment of these requirements needs to be performed before the fixed and firm price for the machine system is agreed.

You have all of this data; so, what do you do with it? The advancement of the use of big data algorithms and data mining in e-commerce, search engines and similar systems mean that many tools are available if the system user knows what they want to achieve. The ultimate goals are more uptime, greater efficiency and lower labour costs to squeeze more out of what is available. It is important therefore to have a wider view of the process and the optimisation the client wants to achieve. This requires people within our client organisations who have the correct skill set (a mixture of production know-how and IT skills) to be able to take advantage of Industry 4.0.

7 Conclusion

Our conclusion from the above assessment is that TQC is already dealing with many of the attributes covered by the Industry 4.0 definitions and the associated analyses published within recent papers on the subject that have expanded the Industry 4.0 concepts and drivers. This process was already in place before we knew of Industry 4.0.

Having undergone our company research into the topic and assessed the elements is detail we believe that we are now better prepared to address the challenges that may arise in the future.

REFERENCES

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2014). How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 8*(1), 37 - 44. Retrieved from https://waset.org/publications/9997144/how-virtualizationdecentralization-and-network-building-change-the-manufacturinglandscape-an-industry-4.0-perspective

Gorecky, D., Schmitt, M., Loskyll, M., & Zühlke, D. (2014). Human-MachineInteraction in the Industry 4.0 Era . *Conference Proceedings of 12th IEEE International Conference on Industrial Informatics (INDIN)*, (pp. 289-294).

Hermann, M., Pentek, T., & Otto, B. (2016). Design Principles for Industrie 4.0 Scenarios. *49th Hawaii International Conference on System Sciences (HICSS)*, 3928 - 3937.

i-SCOOP. (2016). *Industry 4.0: the fourth industrial revolution – guide to Industrie 4.0*. Retrieved from https://www.i-scoop.eu/industry-4-0/

Kolberg, D., & Zühlke, D. (2015). Lean Automation enabled by In-dustry 4.0 Technologies. *IFAC-PapersOnLine, 48*(3), 1870-1875. Retrieved from www.sciencedirect.com/journal/ifac-papersonline/vol/48/issue/3

Lavanya, B., Shylaja, B. S., & Santhosh, M. S. (2017, June). Industry 4.0 – The Fourth IndustrialRevolution. *International Journal of Science, Engineering and Technology Research, 6*(6), 2278 -7798.

Lee, J., Bagheri, B., & Kao, H. (2015, January). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters, 3*, 18-23.

Littlefield, M. (2015, May 18). *What Is Big Data Analytics in Manufacturing?* Retrieved from LNS Research: http://blog.lnsresearch.com/what-isbig-data-analytics-in-manufacturing

Roser, C. (2017, October 3). *Industry 4.0 – What Works, What Doesn't.* Retrieved from All About Lean: http://www.allaboutlean.com/industry-4-0-potentials/

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015, April 9). *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries.* Retrieved from https://www.bcgperspectives.com/content/articles/engineered_pro ducts_project_business_industry_40_future_productivity_growth_m anufacturing_industries

Schmitt, R., Dietrich, F., & Dröder, K. (2016). Big Data Methods for Precision Assembly. *Procedia CIRP, 44*(6), 91-96.

Sommer, L. (2015). Industrial revolution - industry 4.0: Are German manufacturing SMEs the first victims of this revolution? *Journal of Industrial Engineering and Management* , 1512-1532.

Weyer, S., Schmitt, M., Ohmer, M., & Gorecky, D. (2015). Towards Industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems. *IFAC-PapersOnLine, 48*(3), 579584. Retrieved from http://www.sciencedirect.com/journal/ifacpapersonline/vol/48/issue/3

Wittenberg, C. (2016). Human-CPS Interaction - requirements and humanmachine interaction methods for the Industry 4.0. *IFACPapersOnLine, 49*(19), 420-425. Retrieved from http://www.sciencedirect.com/journal/ifacpapersonline/vol/49/issue/19