IRISH MANUFACTURING RESEARCH

MANUFACTURING & THE FOURTH INDUSTRIAL REVOLUTION

Irish Manufacturing Research

2018

Introduction – Evolution or Revolution

We have, over the past 20 years or so, been living through a period of immense change, driven & enabled by digital technology, on this point there is little argument. In some circles however a question remains as to whether an epoch distinction should be made between Third Industrial Revolution and the current era, in other words are we living through a Fourth Industrial Revolution or simply an extension of the Third. The position this paper takes is that yes, we are indeed in the midst of something new and need to recognise it as such. The reason for this stance is that while technological advancement is a necessary element it is, on its own, insufficient to drive an Industrial Revolution, these require the additional realisation of complementary innovations. This can be seen in the emergence of previous Industrial Revolutions, for example in the case of the Second Industrial Revolution, electricity was in wide-spread use in the early 20th century with only incremental improvements in productivity. The reason for this is that the factory design had yet to change from one dictated by the requirements of a steam-powered facility. Manufacturers of the day simply replaced the steam boilers with electrical generators and continued operating as previously. It was only when the incumbent generation began to retire, and a new generation began asking whether there was a better way of doing things that the real initiator of the Second Industrial Revolution – The Assembly Line – was introduced. The innovation was enabled by the increased ease of power distribution provided by electricity but was distinct from the introduction of electricity itself.

This distinction between technological advancement and complementary innovation is often overlooked as the two go hand-in-hand and when viewed with the perspective of hindsight the complementary innovation is seen as an inevitable outcome of the technological advancement and so the two are treated as one (aligned to the technology). While this is a reasonable shorthand when discussing historical progressions, it is detrimental to our perception of ongoing change and has been at the heart of much of the argument about the Fourth Industrial Revolution.

The conflating of technology advancement with complementary innovation, can lead proponents of the Fourth Industrial Revolution into semantic arguments which seek to differentiate the digital technology of yester-year with that of the coming decade(s). As indicated previously, this is an argument that can be had, but is not particularly productive (unless you are in the business of selling next generation technology).

The real question, which will determine whether we are indeed in the midst of a Fourth Industrial Revolution or simply an evolution of the Third, is whether these advancements in digital technology will enable fundament changes in economics, society, politics and indeed manufacturing which will align better with the demands of the evolving Global environment.

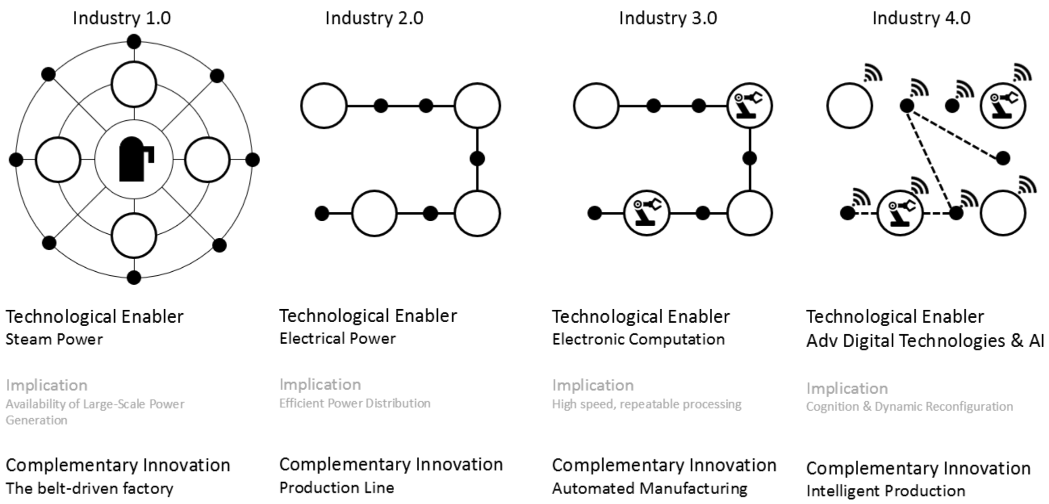

Figure 1 – Paradigms for Industrial production

A Paradigm Shift

The First Industrial Revolution was enabled by the introduction of water and steam power, resulting for the first time in the large-scale mechanisation of manual labor. This mechanisation introduced centralised, volume production and drove a huge spike in urbanisation, marking the end of the agrarian epoch. The Second industrial revolution was enabled by electrification, this resulted in greater freedom in the distribution of power, and variation in production within a single facility, ultimately ushering in the assembly line. The Third Industrial Revolution came with the introduction of computing enabling automation of repeated sequential actions.

Each of these revolutions drove enormous changes in both the factory and society at large, the most impactful of the 3 however was the First. This is because it marked something entirely new and disruptive; the large-scale mechanisation of manual labour. The Second and Third Industrial Revolutions marked changes but were less impactful as their driving technologies led to incremental advancements, they were steps forward but in a previously signaled direction.

The Fourth Industrial Revolution, as with the First, marks a change in direction. For the first time we are faced with a technology-set capable of mechanising human *intellectual* labour. Although, as previously mentioned, the temptation is to consider the Fourth Industrial Revolution as an incremental step beyond the Third, it is in fact closer related to the First in this regard. In all likelihood the Fourth Industrial Revolution and its successors, will ultimately have a greater impact, both industrially and societally, than the first 3, given the deep entanglement between our definition of humanity and our intellect. We therefore stand as the pre-industrial farmers, seeing the smoke rise from beyond the horizon.

Exponential Growth

Not only does the Fourth Industrial Revolution carry with it the capacity for fundamental change but that change is happening and will happen at an unprecedented rate. Once a new technology becomes sufficiently mature, accessible and cheap, novel uses are found for its deployment. Once adopted the new technology will then be adapted to serve yet more applications and so technological advancement progresses (at least in the incremental sense). Two major components in the adoption/adaption cycle are:

1. the rate at which new technologies permeate the eco system and

2. the capability of individuals to envision new applications and the next technological generation.

The Fourth Industrial Revolution is unprecedented in both factors. To understand this from the perspective of the first of these factors, we need only look to what kick-started the Fourth Industrial Revolution to begin with. There is still some indecision in pinpointing the on-set of the Fourth Industrial Revolution, but there seems to be a consensus forming around the early 90's, the period in which the internet began gaining wide-spread popular adoption. The implication here is that, for the first time, an industrial revolution was triggered by, or at the very least coincided with, the adoption of a world-wide communication network. With the internet came a tool of unprecedented capability, in both scale and efficiency, for spreading ideas.

The second factor comes into play in the number of other technologies also currently reaching a tipping-point. Were the internet the only technology to be introduced/matured over the past 3 decades, its impacts would have been immense but perhaps not revolutionary. The internet however has facilitated and accelerated the development of other technologies for example advanced sensors, data analytics, artificial intelligence & cyber security all of which have been integrated with the internet to enable the Industrial Internet of Things. It does not stop there however, additional technologies such as additive manufacturing, adaptive & collaborative robotics and virtual & augmented reality are also all reaching inflexion points in their development and deployment. We also now live in a world of low cost & pervasive compute & connectivity embodied in, among other innovations, mobile technology & cloud computing.

In the Fourth Industrial Revolution, we therefore have multiple technologies all coming of age together, cross-pollinating their advancements, all of which being accelerated by unprecedented interconnectivity. The result of this is exponential technological advancement rates. These rates of advancement, previously unseen, are threatening those who seek to take a "wait and see" approach. Even the concept of "fast follower" requires an enormous amount of ground work to be put in place. Ireland and Irish based manufacturing cannot afford in-action, as each passing month results in increasing ground lost to competition.

A Brave New World

In the summaries of the four Industrial Revolutions, there is a further commonality between the first 3 that is absent from the Fourth. This relates to the main actors in pushing the agenda of the revolutions. In the case of the first 3 Industrial Revolutions, manufacturers were front-and-centre in the technological advancements, in the Fourth, manufacturers appear to be playing catch-up. This discrepancy illuminates a further underlying shift happening as a result of the Fourth Industrial Revolution; how value is added.

In the Fourth Industrial Revolution, the concept of Dematerialisation has come to the fore. Dematerialisation is nothing new, we have been living with it for decades, centuries even. In his book "The Inevitable", Kevin Kelly gives the pre-digital example of the beer can. The basic shape, size and function of the beer can has remained largely unchanged over the past 80 years. This being said, much of the value of the 1950's, tin-coated steel can weighing 73 g has been supplanted by the intangibles of ingenious design and material development, resulting in today's 13 g aluminium cans. Not only that but these intangibles have resulted in additional value beyond the original in that a can opener is no longer required. This value is not delivered through the presence of material but rather through its absence. The onset of the Fourth Industrial Revolution has accelerated this provision of value through intangibles beyond recognition.

Where previous Industrial Revolutions focused on the provision of power and automation in the production of tangible objects, the intangible nature of the digital world meant that early forays concentrated on the service industry, which has experienced endless disruption over that past 3 decades. Companies like Uber, Air B&B and LinkedIn are redefining their markets, able to algorithmically match customer and supplier and economically handle complexity at scale without compromising performance, a feat previously impossible. This capability has resulted in the emergence of the Platform Economy, a new economic model, neither organisation nor market but rather a new way of facilitating customer-suppler interaction. The Platform concept is revolutionising the provision of services and in doing so breaking and redefining the traditionally sacred direct customer relationship.

This model has however already spread beyond the traditional service industry. Providers of what would previously be thought of as physical products are equally recognising the benefits of the Platform business model. Companies like Apple and Google have redefined our interaction with media, turning it from a product that we go to a shop to buy, to a service that we access. The impact of this transition should not be underestimated. The benefits of access over ownership are multiple and manifest on both sides of the interaction; the customer gains access to what they want, when and where they want it and the provider gains ongoing revenue and deep understanding of their customers. If the service is a good one, this symbiotic relationship reinforces itself as the provider can supply what the customer wants before they know they want it. The strength of this business model is enticing increasing numbers of traditional manufacturers and suppliers to reanalyse the underlying value proposition of their products, reimagine their distribution mechanisms and apply the access model to their business. This is largely facilitated through Smart Products (explained in later section) e.g. BMW Go is a service through which access to a BMW car can be gained, when you need it, through your smart phone instead of purchasing a car (this is a clear prototype business model for a world in which cars can drive themselves to your location). The key feature of these new business models is the concept that success in the future will be driven by adding value for your customer through better experience rather than necessarily, lower price.

In this new era of access over ownership, the concept of a fixed product is heavily challenged and rather the idea of "flow" becomes introduced; the continuous updating of products in response to the evolving customer needs. This new, dynamic demand side market puts under pressure some of the foundational tenants of traditional manufacturing, such as supply-side economies of scale and build to stock. Manufacturers, if they are to remain relevant must employ new technologies and methodologies to deliver smaller batch sizes and shorter time to market

Technological Enablers/Drivers

Industrial Internet of Things

The Industrial Internet of Things (IIoT) is a key enabler of the Fourth Industrial Revolution. It is the latest incarnation of the internet and incorporates sensors, networks, big data and analytics. This system collects, processes, stores and analyses data in real time to deliver insights and actionable information.

Up to recently, production facilities operated in silos with minimal communication between the factory floor and other departments in the enterprise. On the factory floor itself, automation has been largely analogue in nature with the use of PLCs and analogue sensors and actuators. With the IIoT mandating new digital infrastructure, connectivity will encompass external suppliers, business partners, logistics and customers in addition to machine-to-machine communication on the factory floor.

Cyber Security

Within the manufacturing industry, the majority of successful attacks have occurred in non-production related departments and this is primarily due to the isolated and predominantly analogue nature of automation on the factory floor.

This scenario is changing dramatically with the roll out of the IIoT. As factories become digitized and IIoT devices proliferate, connectivity options increase, operational technologies and IT systems integrate, and external systems are connected across the value chain, the threat vector and subsequent exposure of an enterprise increases dramatically.

Having strengthened the internal systems in the face of this growing threat, an enterprise must also place its trust in the security of its business partner's systems, external cloud providers, and out-sourced resources. This does not just apply to holy triad of confidentiality, integrity and availability of data, but also an enterprise must maintain the correct level of privacy for its data and the protection of its IP as its systems are exposed.

Cloud Computing

As factories digitize their operations, they will require dynamically scalable infrastructure and access to capabilities, e.g. data analytics. Cloud computing provides this dynamic provision of capabilities.

By virtualizing physical hardware, organizations can commandeer and release resources in response to their needs, utilizing the physical resources in a much more efficient way. The bounds by which the system provisions and de-provisions the available resources provide elasticity and efficiency. Many applications require maximum resources available to them only a fraction of their total uptime, Cloud Computing solutions can assign these resources when needed.

Virtualization also allows the IT infrastructure to be reduced in size and concentrated in fewer places. Conversely it also lends itself to reducing the cost of distributed computing where an application's key components are installed on different servers built specifically to optimize their performance.

Blockchain

Blockchain is essentially a new form of database architecture where data is maintained by nodes in a decentralized network in the form of blocks. Each block in the chain contains a cryptographic hash of the previous block and as the blocks are linked in this way it forms an immutable record of the information/transaction involved by creating a decentralized consensus across the network. The technology's inherent security stems from the fact that to successfully attack and hack the information on the Blockchain, would require simultaneous/coordinated attacks across a majority of points on the network, which is fundamentally different to vulnerabilities associated with traditional networks & database architectures.

Although Blockchain technology has its origins as a fundamentally enabling technology behind crypto-currencies like Bitcoin its potential for broad application across a wide range of areas, like public administration, business, the arts, non-governmental and philanthropic endeavors is becoming clearer with use cases, applications, Blockchain start-ups and ICO's (Initial Coin Offerings) proliferating at a phenomenal rate. This proliferation reflects that the technology, in the lexicon of technology cycles, is probably at the 'peak of expectation' but there is little doubt that the technology will find mainstream application in manufacturing and supply chain in areas such as, decentralized track & trace, real-time democratized updating on condition monitoring and secure exchange of digital assets.

Data Analytics & Machine Learning

Data Analytics (DA) encompasses the processes of inspecting, cleaning, transforming and modelling data with the goal of discovering useful information, suggesting conclusions, and supporting decision-making to create business value. This is hugely important within the Fourth Industrial Revolution because of the significant increase in data availability in recent times and their ability to manage complexity at scale.

Machine Learning, as a discipline of Data Analytics and a branch of Artificial Intelligence, becomes a backbone of The Fourth Industrial Revolution. Machine Learning allows machines to learn from data, by ingesting historic and present data and extracting facts and insights that are hidden in the data and difficult or impossible to find for humans.

The current availability of data, when coupled with Data Analytics and Machine Learning, is transforming the industrial landscape – the ability to control an entire modelled ecosystem automatically brings efficiencies and flexibilities far beyond what has been achievable to-date. This ability to deliver on mass customisation and to be able to respond to issues in real time delivers significant financial benefits, but more importantly, opens the door to entire new business models that are disrupting the current industrial paradigm.

Virtual & Augmented Reality

Traditional displays have developed significantly over the last 40 years, however, they are still bounded by typically 2D rendering and have little awareness of viewing angle. Along with the advancing display technology, location sensors and accelerometers have also received significant development, mostly due to the exploding mobile technology market.

With pixel density increases, huge size and weight reductions, and advancements in sensorisation, head mounted displays (HMDs) with accurate 6 degrees of freedom and realistic and vibrant displays are becoming far more abundant and practical. Transparent displays have also opened the same technology to Augment the wearers view by adding visuals locked to real world positions.

Coupled with hardware developments, graphical computation and rendering has also reached photo-realistic quality on consumer level hardware, and the development of 3D environments and components is becoming more attainable.

All of this together enables accessible, industry ready Virtual and Augmented Reality solutions, delivering fully immersive virtual environments, and real-world, location-specific interactables, which can be applied in almost any area within a modern facility.

The result is a new technology, ready to make game-changing improvements to the way we view and interact with machines and their data, upskill, communicate and work.

Adaptive & Collaborative Robotics

Adaptive Robotics is an emerging term that captures the changing nature and role of Robots in industry. The presence of Robots in manufacturing is nothing new and has been the norm in some sectors, e.g. automotive for some decades. These traditional instances of Robotics are however characterised by the static nature of their environment. These traditional installations of Robotics involve the pain staking creation of models which operate as proxies for the physical world, overlaid on these are the processes to be carried out. The environment and surroundings (including incoming raw materials) are then highly controlled to ensure persistence in the relationship between the model and the physical world. This approach is appropriate for high volume manufacturing as it leverages the robot's accuracy, speed and ability to operate in harsh environments, however it makes flexibility cost prohibitive.

A new paradigm is emerging however, that of Adaptive Robotics. Adaptive Robotic Systems, rather than utilizing fixed models and controlled environments, employ continually updated, dynamic models facilitated through direct perception of the physical world. If this perception is carried out appropriately and regularly enough (terms which are relative to the application), this approach, in theory, negates the need for a priori modelling. The dynamism of these systems coupled with their relative ease of set-up opens entirely new application spaces for Robotics in Manufacturing. These new application spaces include, but are not limited to:

- Human-robot interaction & collaboration;

- Applications involving variability in product size, shapes, position, orientation, etc;
- Complex tasks such as assemblies;
- Lower value-to-volume ratio applications.

Additive Manufacturing

Additive Manufacturing is the creation of parts through the incremental, layer-by-layer addition of material. Additive Manufacturing exploits this new method of production along with modern computing and Computer Aided Design to mitigate problems faced by traditional manufacturing methods, allowing the introduction of new, innovative products into the market faster and more cost effectively.

Among the transformative attributes of this technology is its ability to produce complex geometries, cost effectively in batch sizes as small as single pieces and its almost zero reconfiguration time. Early adopters of this technology include those producing products which benefit greatly from personalization e.g. orthodontic aligner and hearing aids. However, addition interest is quickly growing among manufacturers seeking to consolidate complex assemblies and those seeking to gain benefits from light weighting (the principle of redesigning products' physicality, placing material only where functionally required) of products.

Cyber Physical Systems

The above sections describe quantized pictures of the technological drivers of the Fourth Industrial Revolution. The true transformative nature of these technologies only becomes apparent however when they are utilized in conjunction with each other. A key combination architecture is the Cyber-Physical System. A Cyber-Physical System (CPS) is a combination of a physical asset (such as a machine or production line etc.) and software (typically in the cloud) that are connected, exchanging real-time information with each other. This connection between the physical and the cyber space provides augmented performance for the physical assets and opens new possibilities in manufacturing.

Impacts in Production

In the Board Room

Platform Development

Since the beginning of the Fourth Industrial Revolution we have seen the emergence of technological systems capable of sensing, communicating, cognifying, and acting on the physical world. This combination of technologies closes a loop without any human input and as such allows interventions to take place at scales, scopes and speeds never before seen. Early implementations involved only 2 of these capabilities (communication and cognification) but have already lead to a complete redefinition of how markets work and how people interact.

As mentioned previously a Platform is neither a company nor a market but rather something between the 2, never previously possible. A Platform offers an infrastructure through which 100's of thousands, if not Millions of contributors and consumers are dynamically matched and rematched in an enormously complex interaction. The Platform model flips most organizational structures on their head, rather than the traditional top-down structure of yesteryear, a Platform encourages, indeed replies upon, a bottom-up structure (with "just enough" top-down organization, provided algorithmically). This new model, often monetized through subscription models, if properly executed, is intrinsically dynamic, agile and scalable. It forms a symbiotic relationship between the service (Platform) provider and the customer. From the customer's perspective, their needs are met with minimal effort (often no effort) and at greatly reduced cost and from the Platform's perspective they get ongoing revenue stream and deep understanding of their customers which allows them to provide better customer experience which reinforces the relationship.

The first industrial sector to fall victim to the power of Platforms was the service industry. Traditional industries made up of monolithic, centrally controlled organizations providing services of all descriptions were disrupted by agile distributed organizations based on the Platform model. Examples here are the retail industry disrupted by Amazon, the taxi industry disrupted by Uber and the accommodation industry disrupted by AirBnB. The depth of these disruptions is such that these companies have become household names.

The technology has, at this stage advanced sufficiently that the activities of sensing and augmenting the physical world have now become sufficiently advanced and affordable that tangible products now face a similar fate as services and as with the providers of services, manufacturers need to examine how they will respond.

As products become "Smart" and usage data guides increasingly short product and design cycle times, those who will survive are those who can respond most quickly and with the greatest flexibility, allowing them to integrate into the Platform Economy.

In the Market Place

Smart Products & Servicisation

Touted as one of the pillars of the Fourth Industrial Revolution, Smart Products promise to revolutionize how we access and engage with products. A Smart product is one which has been augmented with sensors to monitor its key performance and usage metrics and communication capabilities to report these back to base. The data drawn in from products in the wild informs subsequent product designs, product maintenance and future offerings. Key impacts of Smart Products are the extension of the Platform Economy to tangible products and a transition from product sales to service provision. An example of this might be micropayments per litre pumped instead of purchasing a pump outright.

In the Supply Chain

Supply Chain Integration

Supply chain management (SCM) has been traditionally concerned with the acquisition, condition, movement & security of physical materials, goods & equipment across the factory network and between the enterprise entities (suppliers, partners & customers) that comprise the full value chain. This will continue to be at the core of SCM but in a 'Future Supply Chain' context it will be increasingly concerned with digital assets, digital twins that represent the physical world in a virtual & cyber-physical business environment.

Digital twins are central to Additive Manufacturing and with AM's potential to deliver mass customization and disrupt economies of scale, securely shipping digital assets within the network will become as central to SCM as securely shipping physical product is today. Blockchain's distributed ledger technology with its inherent security capability may become a new paradigm not only in enabling secure exchange of digital assets but in enabling transactions (crypto and/or FIAT) and real-time updates across the network regarding, location, condition & security.

IIoT with connected products, factories and supply chains and its capability to dramatically increase supply chain transparency & visibility through real-time and relevant data input into resource, capacity and materials planning has massive potential in creating truly responsive enterprise capabilities.

In the Factory

Reconfigurable Production Flow

The promise of the Fourth Industrial Revolution is that of systems delivering Mass Customization and minimal time-to-market for new product lines.

At the heart of this is a move towards Software Defined Infrastructure (SDI) where the flow of material within a facility can be changed on the fly consistent with the moment-by-moment demands of production. In this paradigm, current concepts of material flow, informed by our systems of conveyer belts, tracks and rails becomes replaced with a completely flexible and reconfigurable internal logistics systems. Here, Work In Progress (WIP) can travel between any 2 stations depending on the immediate need of the pieces and/or the optimum utilisation of production capabilities.

Processing norms will also be disrupted. Today's practices are based on tight control of input parameters and application of standardised processing treatments, which have been modelled or shown to result in the desired output for the largest possible proportion of the units created. This approach (with improvements) has been the norm since the 1920's with the introduction of Mass Production. This system however results in a high cost for excursions from the norm, whether from input quality or process variation and enforces a trade-off between productivity & product variety.

In the new paradigm, processing will be dynamic, no 2 products will get exactly the same treatment as the processing will be adjusted in-process, to deliver the desired output on the basis of current conditions and input parameters. This dynamic processing will result in near 100% yields and tolerance to variability in conditions and inputs.

IRISH MANUFACTURING RESEARCH

Where to begin?

While the promise for The Fourth Industrial Revolution is the convergence of multiples technologies, leading to never before seen practices, this is too much to bite off in one go. The scope, scale and depth of the Fourth Industrial Revolution, to say nothing of its on-going nature, implies that the best approach for many organizations is that of incremental Innovation.

Initial forays should use digital capability to address today's problems. The introduction of sensorisation on problematic tool-sets or implementation of rule-based digital interaction on systems or processes can deliver enormous organizational value through transparency and efficiency benefits respectively. These can be delivered and implemented before consideration of whether and where AI supported decisions can be leveraged to best effect. This approach also allows the organization in question to build their digital capabilities at a more organic pace.

Additionally, an organisation's efforts should initially be confused on that over which they have greatest control, their internal systems (Vertical Integration), before expanding out into their supply chain (Horizontal Integration) and initial investments should deliver immediate value, should be integrated in the organisation's wider systems and should provide stepping stones to further interventions. A contextualized Vision of the organisation's future state, built on a foundation of manufacturing fundamentals, is therefore a key element of extracting maximum value from investment.

In this context the following steps are advised:

1. Align around a Common Vision

   A commonly shared and aligned vision for the organization is needed to provide a North Star, this should be ambitious, be representative of the organisation's values and clarify objectives

2. Identify Use Cases

   Investments in next generation technology will by their nature elevate the organizations capabilities but they should also solve today's problems. Gathering a list of potential use-cases will reveal the scope of opportunity available on the journey. This list should be updated periodically.

3. Prioritize Use Cases

   On the basis of business needs, prioritize the Use Case List with a view to Desirability, a sub-component of this should be the consideration that fixing the problem statement will deliver sufficient returns as to justify a reasonable investment in the solution.

4. Assess Maturity Levels & Create a Roadmap

   Here the technological and capability (work-force) maturity of the associated area needs to be assessed, at least for the top few Use Cases identified. This will help you understand the Viability of an intervention and indicate where the next natural Maturity step lies.

5. Demonstrate Early Wins

   At this point, you will have compiled a short-list of challenges to tackle which are Desirable, Feasible and Financially Viable. The next step is to pick a first Use Case and act on it.

6. Engage Others

   Hopefully this document has, if nothing else, hinted at the scale of the opportunities & challenges which will arise in the coming years. This endeavour cannot be undertaken by 1 person. As early wins demonstrate value, you must engage others, grow your Coalition and build on this foundation.

IMR can assist organizations in any or all of these steps, employing Innovation tools, deep domain knowledge in the key technological areas and in excess of 400 years of combined industrial experience.

Conclusion

We stand in the midst of uncertainty, as the next major Revolution in human experience unfolds around us. The evidence points to the fact that taking a wait-and-see approach will likely result in significant risk of digital disruption for most organizations. Equally the prospect of trying to predict where this will end and investing heavily on that basis is not an option either. However, there is a third path, that of incremental investment toward a vision. This is an option open to all and a journey on which IMR can support you.

Ken Horan
PhD, MEng, BSc

Industrial Research Lead
Industry 4.0 & Cobotics

M: +353 87 093 7368
E: ken.horan@imr.ie
W: www.imr.ie