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Understanding Industry 4.0 Digital Transformation

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Abstract

The concept of Industry 4.0 has motivated large engineering sectors towards a common focus for improvement. Academics have capitalised on the common language, shared motivation and marketability of Industry 4.0. The potential and perceived benefits of Industry 4.0 are clear within academia and beyond. However, are engineering companies ready for the digital transformation associated? and, can Industry 4.0 be achieved by SMEs? In this paper, we investigate these questions through activity on project road mapping with 4 Scottish companies to reveal Industry 4.0 readiness and literacy.

Keywords: digital transformation, project planning, project management, industry 4.0, supportive technologies

1. Introduction

Digital transformation is an ability to change when opportunities arise or are needed, using technology as a means. Technologies commonly associated with industry 4.0 are often viewed as novel and contemporary to overcome modern challenges. Companies are often unprepared for change due to day-to-day demands removing the ability to prepare, or the foresight of what may be coming. To understand digital transformation, we must also understand what drives these changes, how transformation takes place and how prepared are companies for change.

Within the UK, the transition to Industry 4.0 faces the same challenges as around the world including "…adaptability and agility in rapidly reconfiguring its [the companies] manufacturing systems in response to the changing demands of both global and local markets ... this integration would extend to the smart supply chain that would benefit from the digital connectivity, building competitiveness within the UK SME (Small and Medium Enterprises) base, enhance UK skillsets, and overcoming the 'disaggregation of OEM procurement' by onshoring to UK smart supply chain." (Duffy *et al.*, 2016).

Pessôa et al., (2020) details the motivation from Industry 3 to Industry 4.0 spurred by technological and social advancements of: the internet, acceptance of enterprise resource planning, demand for smaller batches and wider variety of products, ease of customer relationship management, ease of complex value chains, lean product development and better understanding of quality, health, safety, and environmental aspects. Of particular interest is the desire identified on changeability stating "designers should be able to understand what might drive future changes in the product and then decide on changeable solution architectures. This requires educating designers about design options and determining whether and when these options should be executed during the product's use phase"(Pessôa *et al.*, 2020). To act on this reflection requires continual education on new Industry 4.0 potentials, perhaps through self-study or organised educational interventions. Which the motivations from Industry 3 to 4.0 can be characterised in its current state, it must be noted that these will not be the same characteristics in years to come. To keep relevant, engineers must be continually seeking new potentials.

Hussain et al., (2021) reflects on the challenges that COVID-19 has created and how Industry 4.0 can support business continuity. Two questions answered within the paper are: which major challenges can be resolved by Industry 4.0 technologies? and what is the potentiality of Industry 4.0 technologies to resolve these challenges for long term sustainability? These are two key questions to answer to understand readiness for digital transformation. The authors identify technologies including autonomous robotics, big data analytics, systems integration, internet-of-things, flexible manufacturing, augmented reality, cloud computing and additive manufacturing. These technologies have the potential to overcome post pandemic challenges through capabilities of functional compatibilities, decentralised controlling capability, virtual capability, data, smart services orientation, flexible systems, and modularity of systems. These are significant findings for COVID-19 recovery, but also all other future pandemics and pandemic like situations that a company may find themselves in.

Schneider et al., (2020) present a model for the implementation potential compared to the actual state of Industry 4.0 for a company. Certainly, the model is a well-considered and includes the expected criteria to support forecasting. However, when compared with implementations of other such tools in a Scottish setting, such as the Scottish Manufacturing Advisory Service - Manufacturing 4.0 Review), or the Advanced Forming Research Centre - Automation review there is a need to support education for accurate use and correct understanding of the outcomes of these tools.

To better understand Industry trends towards 2040, Eckert et al., (2019) conducted workshops with experts of Industry in the UK. One key outcome identified in multiple areas is supporting education of engineers. Towards tackling future societal challenges experts identified "a need for support tools that can increase the knowledge of the engineering teams in the early design phases regarding the product´s lifecycle implications, including information about material and energy issues." They go on to state that through simulation and visualisation and models engineers can better understand the "social behaviour, societal needs, and policy changes" of the future.

Pessôa et al., (2020) describe ten key findings, derived from the literature identified to directly impact the design-engineering process for Industry 4.0 transition. These are design for empowered users, design for product-in-use feedback, design for changeability, design for data analytics, design for cyber security, design for emotional interaction, continuous engineering supported by Model-Based Systems Engineering (MBSE), system lifecycle management, increased stakeholder quantity and complexity, changes in quality perception. These identifications are a mixture of good practice in product development, critical skills for an engineer to build and identifications for greater awareness and education, such as, "towards design for changeability". The authors go on to specify.

> *"The design-engineering team must be educated in IT related subjects, particularly in data modelling, data analytics (including artificial intelligence approaches), the IoT and cyber security. Knowledge of systems engineering and particularly model-based approaches such as MBSE, will support the understanding and synchronisation of several disciplines involved in design and development. Finally, each team member must be aware and concerned about ethics, privacy and user-data confidentiality issues." (Pessôa et al., 2020)*

For companies who engage in engineering challenges, this raises the question of how will they gain this knowledge? How will they continue to gain new knowledge without repetition? How will they know when to pause/stop? Eckert et al., (2019) suggest that the answer may lie with these new technologies.

> *"Learning with digital tools: Robots, AI systems, augmented, virtual and mixed reality (AR, VR, MR) will make it possible to move learning methods to new heights, in experimental ways. However, it is required that continuously developed specialist knowledge is built in to the new technology tools, and there is an apparent risk if too static and simple, already known knowledge, is the only basis for these tech learning tools."*

This highlights that novel methods of educating can have a limited impact, however the knowledge educators are imparting on 'students' about these novel technologies is the key factor. The argument has been set for better education on Industry 4.0 potentials and how to evaluate and implement potentials.

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This paper describes the development of a course for Continuing Professional Development (CPD) in digital transformation towards Industry 4.0 and the delivery of this course to four Scottish companies. The outcomes of a course activity are discussed being a road map towards the implementation of an Industry 4.0 solution.

2. Methodology

In response to prominent calls in 2019 from the likes of Forbes, Institution of Mechanical Engineers (IMechE) and the Scottish Government, a CPD course was envisioned to support strategic technology selection for Scottish engineering companies. Surveys determined a lack of foresight for digital transformation in business leaders (Welsh, 2019) particularly when the number of digital natives within companies increases year on year. In an IMechE survey prepared by BDO of 318 UK business leaders, only 8% had a good understanding of Industry 4.0 and 56% had little or no understanding (BDO LLP, 2016). NMIS identified this as a strategic development opportunity.

The CPD course was aimed as a strategic level course designed to support awareness of the potential of digital technologies to improve engineering processes. Five questions were derived to support the development of the course supporting Scottish engineering companies to begin their transformation:

- How to respond to drivers for digital transformation change?
- Which technologies are out there to be aware of?
- How to stay up to date?
- How to manage change?
- What skills and capabilities are required?
- Which tools can help?

The CPD course would aim to answer all questions above including a mixture of academic literature, popular business literature and case study examples from NMIS partners. The course was designed to go beyond that which had been developed at the time, answering the real-world issues that faced Scottish Engineering including how to implement incremental development and rationalising business cases.

The course format was as follows

- An introduction to Industry 4.0 and drivers for digital transformation including decision making and collaboration.
- An overview and discussion on Industry 4.0 technologies including robot assisted production, predictive maintenance, additive manufacturing of complex parts, machines as a service, big data drive quality control, production line simulation and smart supply network with a focus on Internet of Things (IoT), Artificial Intelligence (AI), 5G, augmented/virtual reality AR/VR, additive manufacturing, and robotics.
- Guest speakers to detail real world industry 4.0 case studies inspiring actionable changes for digital transformation including digital twin systems and AR for staff training.
- Tools and techniques for implementing digital transformation change including road mapping, profiling technologies and project planning, and.
- How to stay up to date with digital transformation including signposting to support companies in Scotland and UK wide.

The course sought to build the delegates knowledge on digital transformation to ensure a common understanding to complete course activities.

2.1. Design of the road mapping activity

The course involved a road mapping activity introduced from a perspective of project planning in which delegates were prompted to consider how best to implement a digital transformation.

An example was provided to delegates of a scenario which requires a digital transformation. In the example, '*An electronics remanufacturer takes old computer hardware and installs new components to create modern, capable, machinery for schools. The remanufacture requires a mix of manual and automated tasks. Many bottlenecks exist in the process. Staff numbers are low and multiple staff are required to perform different tasks to alleviate repetition. The company wants to implement an alert*

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system which can track product as it flows through the production process and inform staff of production levels'. The example was discussed with delegates who are guided to the solution of a sensing and alert system. Multiple sensor types are required for the desired outcome and both automatic and human input is required. The solution will enable monitoring of bottlenecks to discover why the bottlenecks occur and how to stage an intervention.

A template was created to guides delegates to make a full consideration of the new system including defining the scope and boundary of the system, skills and leadership requirements, and the need for validation and continuous improvement. Delegates were asked to consider the planning topics in the following order:

- Preliminary activities,
  - Essential conditions,
  - Learnership support,
  - Scope and boundaries,
- Development,
  - Define,
  - Technologies,
  - Timeline/milestone,
  - Requirements,
- Implementation,
  - Validation,
  - Reviews,
  - Updates.

To encourage collaboration between delegates and promote multi-disciplinary inclusion in digital transformation, a template was created for the activity (Figure 1).

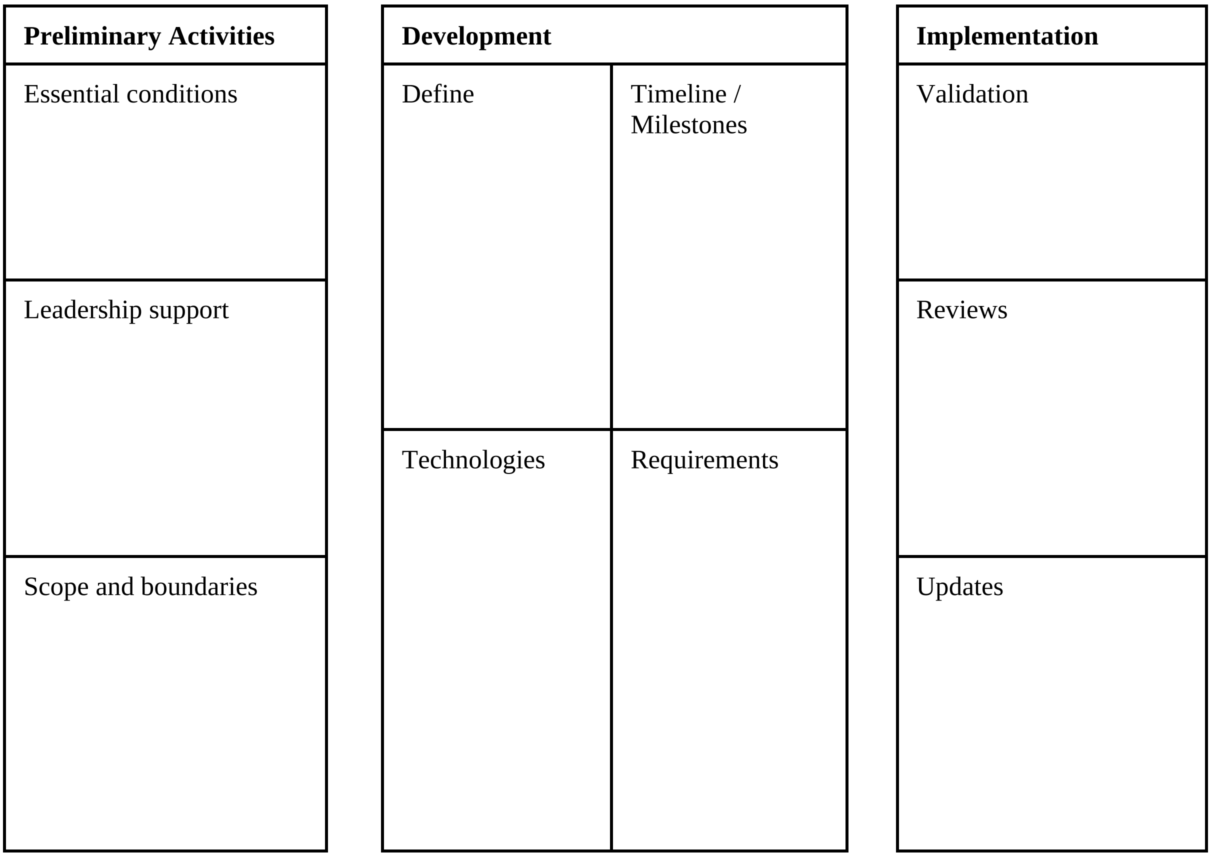

Figure 1. Template for the digital transformation project planning activity

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2.2. Industry participation

The four companies involved in the course activities were a multinational aerostructures manufacturer [Company A], a multinational naval and maritime manufacturer [Company B], a medium sized manufacturer of fishing products [Company C], and a small design & product development company [Company D].

Company A operates across five countries supplying the big two aircraft manufacturers with fuselages, wings, and other components. The company has between 15k and 20k employees worldwide. Company A has worked with DMEM on several CDP, Continuous Improvement (CI), Knowledge Transfer Partnership (KTP) and other projects in the past.

Company B operates across ten countries in four key areas of marine, nuclear, land and aviation. There are around 35K employees worldwide and DMEM has strong relationships with Company B through decades of student projects and CI projects.

Company C are a Scottish based design and manufacturer of fishing products including rods, poles, reels, and other accessories. The company has an average turnover of £20 million however they do not provide an estimate of company size. The company have had limited interactions with the university.

Company D are a Scottish design & product development company with one cycling accessory product in retail. The company has less than five employees and has strong relationships with DMEM as one employee is also a member of staff.

Company A and B had previous experience with digital transformation through CI projects. Both had established and successful CI teams, process, and procedures to introduce new ideas to the company. In addition, both Company A and B had experience with road mapping to achieve Industry 4.0, however delegates from both companies reflected that the transformation as detailed in the road map was so large, they struggled to implement practical change in the short term and to map out the steps of the process.

Company C and D did not have active CI teams or projects ongoing. Company C reflected that for such a small company they don't have the time or capabilities to dedicate time towards improvement. This sentiment is also reflected in Schneider et al., (2020). This sentiment is reflected across small and medium companies who are struggling to make actionable change and take advantage of technology advancements. Further research is required to understand the impact to those companies who cannot keep up with the pressures of change and the best ways to support companies to remain competitive.

3. Course Activities Outcomes

The worksheets created by the companies during the course activities have been digitised for clarity.

Company A produced a road map for the digital transformation of one component in their aerostructure product (Figure 2). The delegates of the course identified key findings specific to their process such as 'research tracking and alarm system' and the need to find specific technologies 'alarm system' and 'detection system'. Generalisable transformation key findings include the need to 'establish KPI's', 'confirm buy in', 'Confirm resources…' in particular IT for digital transformation and the 'software requirements' and 'identify available funds'. Company A detailed a plan for implementation with the following steps: '… base line measurement, pilot, compare, document lessons learnt, how often do we review'. The only validation identified by the company was the removal of bottlenecks i.e., has the situation been improved. Delegates indicated a final step, to handoff to a continuous monitoring team.

Company B produced a road map for the digital transformation of a production line tracking and alert system for a large-scale component in ship building (Figure 3). The delegates of the course identified key findings specific to their process such as 'capacity analysis', 'alert system', 'decision making system' and the implementation of the company wide 'phase gate process'. Generalisable transformation key findings include the need to seek 'budget approval', 'identify skills/resources', gaining 'staff buy in', 'communication', 'IT support', an 'executive sponsor' within the company management team, a 'prototype', 'sponsor reviews', and 'data snapshots'. In conducting the road mapping activity, the delegates identified issues with their Industry 4.0 digital transformation including that the project had to fit within the existing 'production process', and they had to find capacity to conduct the project. Company A detailed a timeline for conducting the development of: 'evaluate current research', 'evaluate technology', 'select technology', 'pilot', and 'implement'.

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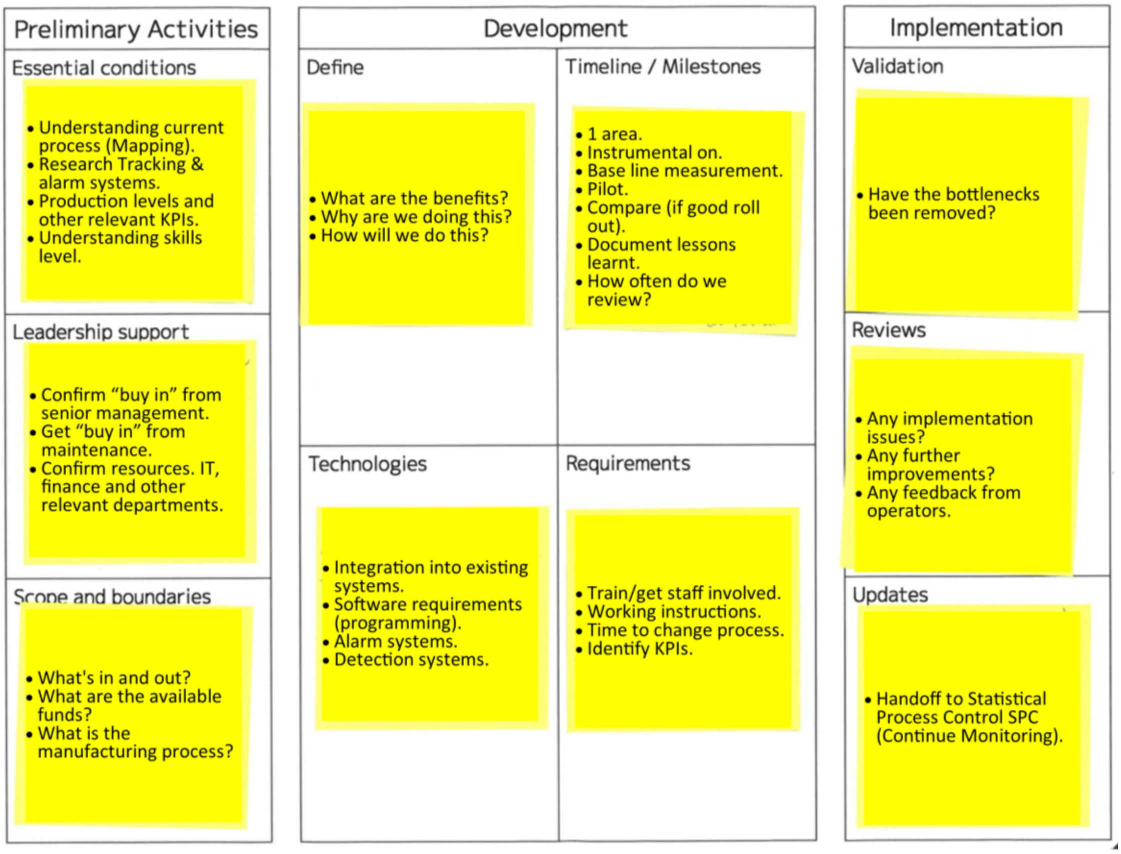

Figure 2. Outcomes of the company a road map.

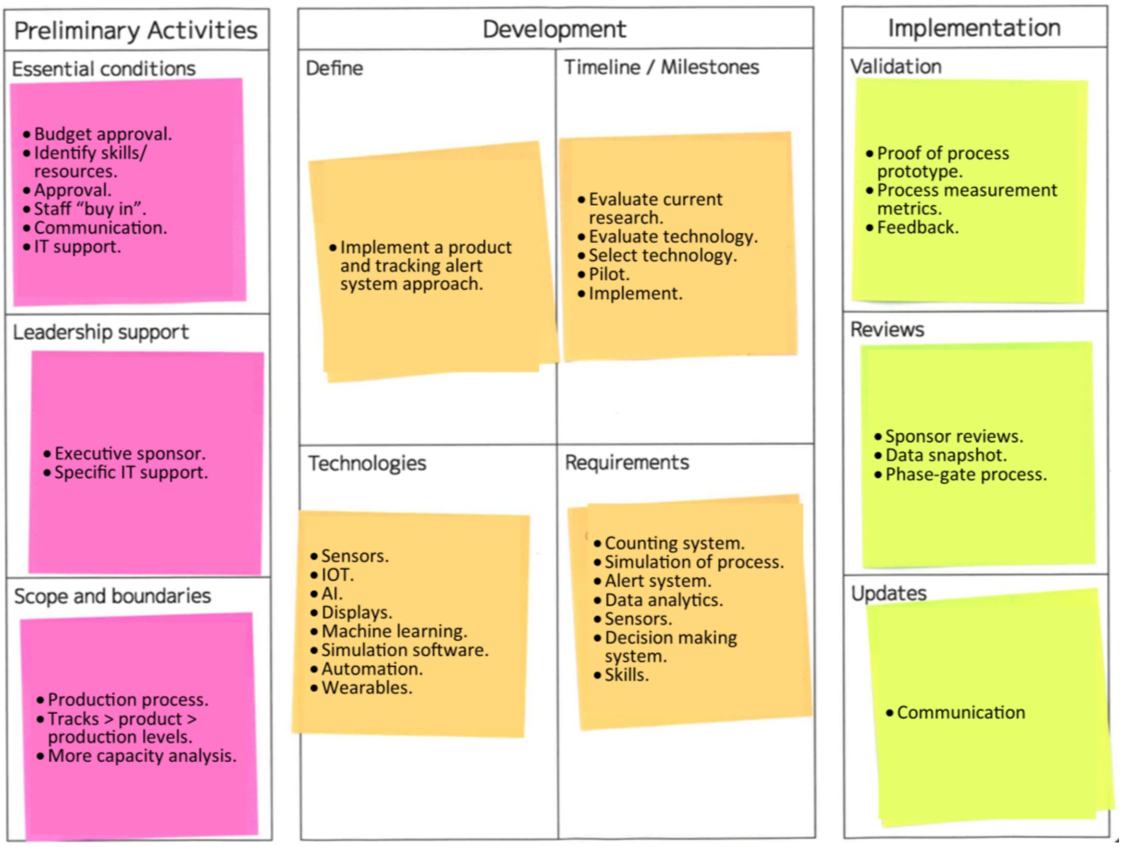

Figure 3. Outcomes of the company B road map.

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Company C & D produced a road map for the digital transformation of a fishing rod product (Figure 4). As company D did not have any active products in development, they supported Company C in the role of a consultant. The delegates of the course identified key findings specific to their process such as 'Environmental', 'social' and 'financial' conditions, 'ownership' particularly in the context where consultants are involved in the product development, 'Make-Buy analysis', and 'futureproofing'. Generalisable transformation key findings include the need to define 'reasons for R&D', 'define measurables', return on investment 'ROI', 'assign maturity lead', 'performance against baseline', 'customer specification', and 'technology as defined by budget'.

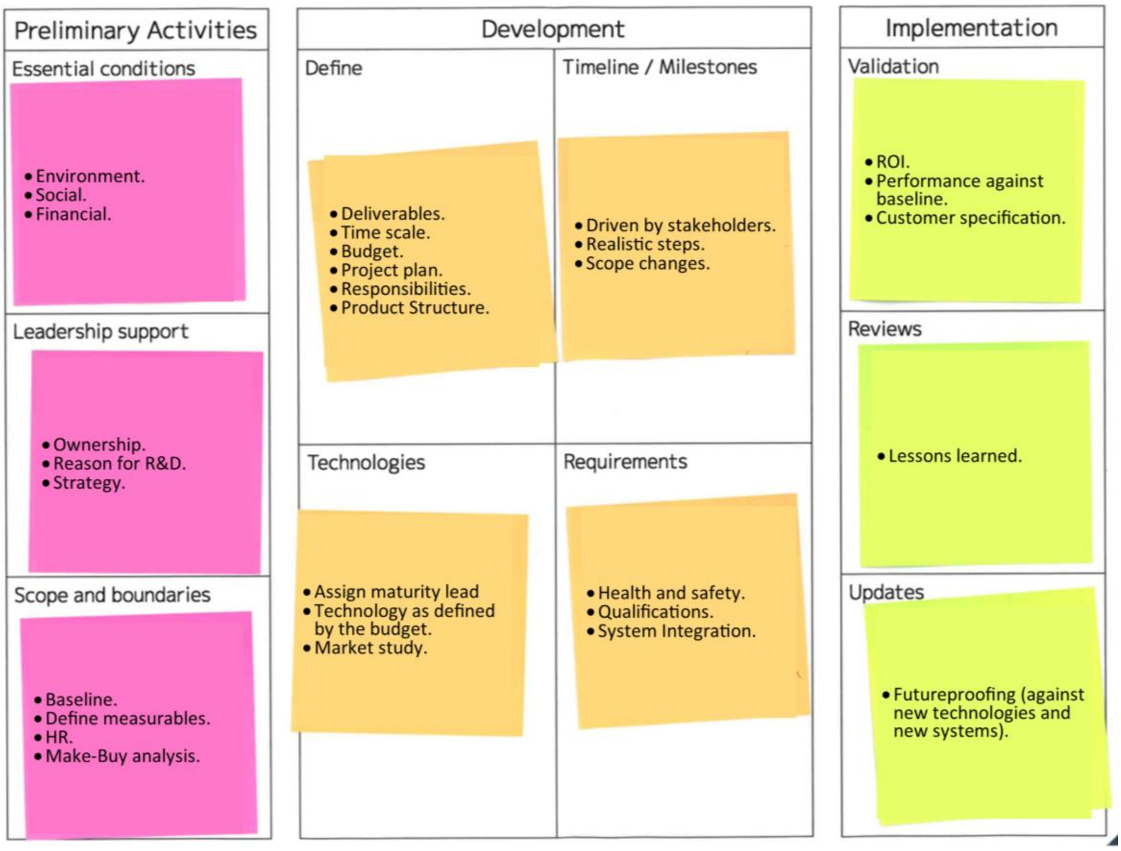

Figure 4. Outcomes of the company C & D road map.

4. Discussion

The outcomes of the road mapping activities reveal the industry 4.0 understanding for each of the engineering companies at different sizes. Future CPD courses will allow the findings to be confirmed and generalisations to be made. The outcomes of the course partially reveal the readiness of each company based on their understanding of how to implement industry 4.0 within their company. To fully understand the readiness level there also needs to be assessment of how change can be actualised in the company e.g., are process, procedures, and a willingness to change in place? Future collaboration with these companies can determine this however their attendance at the CPD course indicates their willingness to change.

Comparing the road maps for each company, the larger companies (A & B) had a greater understanding of industry 4.0 and how to enact change. Delegates from these companies highlighted the need to establish KPI's, implement the companies phase gate process, and to handoff the project to a continuous monitoring team. Each of these interventions indicates already established change management protocols within the companies. In comparison, the smaller companies (C & D) had a focus on turnover including Make-Buy analysis, customer specification and technology as defined by budget. Delegates from the larger companies had a mandate for continuous improvement and used Industry 4.0 to move towards a more productive state. Those from the smaller companies were more focused on day-to-day

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activities and could only justify improvement if it were required for a future project or if a supplier demanded change to integrate with their systems. This puts a disadvantage on SMEs located in Scotland who cannot grow limited by their competitive position.
Another finding which matches this sentiment is the identification of future proofing by Company C & D. The term indicates that there needs to be a minimum viable use of a technology to justify its purchase e.g., it will remain relevant for 10 years. With the speed of technology change this is perhaps not guaranteed by industry 4.0 which seeks continuous improvement. Again, this puts smaller companies at a detriment.
All companies highlighted there was a need to identify available finds or for budget approval. However, the smaller companies framed this in the perspective of return on investment. When implementing new industry 4.0 technologies the purpose may be to justify more productivity and therefor a fast return on investment. However, the motivation for a move to industry 4.0 may not support a productivity increase and may be motivated by outside demands. This means that a return may not be achievable in the short term.
Company A & B identified the need for staff and management "buy in" or commitment to the project before moving forward. This means preparing a justification for the project. Company C & D were more concerned with how to justify the project to their customers perhaps as a way of indicating they are a more technologically advanced company or justifying a higher price for its products. There did not seem to be any recognition that change has to take place to remain competitive.
Both large companies identified that significant IT support would be required for any digital transformation within the company including integration with existing systems. This may allow for lower cost interventions to be implemented. Company C & D looked for a complete system that would enable to technology to be installed and run independently. The approach identified by Company C & D would certainly be of a higher initial cost and high ongoing support costs. This again puts the smaller companies at a disadvantage to make change.
On discussing the findings with the companies, Company A and B have been through digital transformation road mapping before and reflected that the high-level road mapping left them with more questions than answers. It was not clear how to move forward towards the designated state through a digital transformation. Using the worksheet to road map an individual product enabled them to focus on achievable interventions within the company highlighting the need for projects specific road mapping beyond strategic level development.
The worksheet focusing on transformation of a product, as apposed to transformation of a company's capabilities/or a site transformation supports the pedagogical level of those positioned in the company to plan the implementation towards Industry 4.0. To tackle digital transformation for a higher level, perhaps from the perspective of an academic advising on digital transformation raised cognitive barriers.
Company C confirmed they are focused on measurable improvements that can be justified to customers and were beginning in their transformation. However, many of the interventions identified could perhaps be classified as industry 3.5 (somewhere between industry 3 and 4.0) than 4.0 including interventions such as automation of the assembly line.
One notable difference between Company A and B was the difference in implementation. Company B identified the need for a prototype, review, snapshot and then implementation into the existing process. Company A considered digital transformation as a new process that would replace the need for the existing process. The approach of Company A would enable more radical change and implementation of completely new systems where Company B may be constrained in their technology selection due to what is achievable with the current scenario.
Company C & D identified ownership as an important consideration perhaps due to the nature of company D as a consultancy. This raises questions of data ownership that need to be resolved when external stakeholders are involved. Certainly, moving into the future, more data captured would indicate greater considerations from a legal standpoint.
Each company involved created a process of how to implement their change. Company C & D highlighted considerations for the implementation of their change rather than steps for the change itself, this reflects the state of readiness of these companies who are early on in their journey towards Industry

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4.0. Company A and B were able to produce robust plans for an example timeline for their chosen Industry 4.0 project.

Company A & B had different approaches to completing the road map. Company A focused on the process to implement the digital transformation in contrast to Company B who focused on the technology available. This reflects the outlook of each of the larger companies. The employees from company A were empowered with implementing a digital transformation to improve processes and did not have to focus on justification. Company B had more responsibilities to justify an intervention and with a focus on available technologies, they could identify and justify more potentials for improvement. From Pessôa et al., (2020), The motivation for digital transformation have been acknowledged by the companies involved in the course in particular acceptance of enterprise resource planning and ease of complex value chains. No companies involved considered the product road map from the perspective of the customer or the requirements. In its place, the companies focused on acceptance of change within the company justified by a business competitive need. This aligns with the focus of (Pessôa et al., 2020) on identifying drivers for future change which may be counteractive to the change required immediately. Hussain et al., (2021) identified a major question in digital transformation for industry 4.0 being which major challenges can be resolved by Industry 4.0 technologies? Companies A & B took this approach to best understand the technologies and their potential. Company C being the SME focused on day-to-day problems and conducted research into the best ways to solve these problems. This means that the opportunities for continuous improvement were limited as knowledge of potential interventions were unknown. Companies A and B are in a better position to address challenges through a knowledge of the potential of Industry 4.0 technology functionality.

From analysis and discussion with the companies, there was limited justifiable knowledge to support the view of Eckert et al., (2019) that the tool provided can support a better understanding of future social behaviours, societal needs, and policies. Companies A, B, C & D demonstrated a focus on the company and not the larger implications for society. It remains a motivation of the CPD course to encourage engineering companies towards making ethical and sustainable decisions however it is unclear how to encourage this through course activities.

5. Conclusions

This paper details the outcomes of a CPD course and integrated activities on Strategic Technology Selection for digital transformation. The outcomes of the course activities reveal the approaches to digital transformation of two large engineering companies, one medium sized and one small company. The approach identifies that small and medium sized companies are at a disadvantage when it comes to implementing industry 4.0 interventions and digital transformation initiatives. Unless driven by a customer requirement or project requirement, interventions are likely not to be considered. This may bring the company to a negative competitive position. Through awareness of industry 4.0 technologies, these smaller companies can begin to understand positive interventions to stay competitive, however motivation and time is limited to achieve this. The two larger companies were very aware of what Industry 4.0 is and the types of digital transformation interventions that they could implement. Road mapping at a company wide level supports strategic planning, however, individual interventions are difficult to envisage which a project road mapping activity was able to support.

Acknowledgements

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