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Article

Smart Systems Implementation in UK Food Manufacturing Companies – A Sustainability Perspective

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Abstract: The UK food industry faces significant challenges to remain sustainable. With major challenges such as Brexit on the horizon, companies can no longer rely on a low labour cost workforce to maintain low production costs and achieve economic sustainability. Smart Systems (SS) is being seen as an approach towards achieving significant improvements in both economic and environmental sustainability. However, there is little evidence to indicate whether UK food companies are prepared for the implementation of such systems. The purpose of this research is to explore the applicability of Smart Systems in UK food manufacturing companies and, to identify the key priority areas and improvement levers for the implementation of such systems. A triangulated primary research approach is adopted and includes a questionnaire, follow up interviews and visits to thirty-two food manufacturing companies in the UK. The questionnaire and interviews are guided by the development of a unique measuring instrument created by the authors that is focusses upon SS technologies and systems. This paper makes an original contribution in that it is one of few academic studies to explore the implementation of SS in the industry and, provides a new perspective on the key drivers and inhibitors around its implementation. Findings suggest that the current turbulence in the industry could be bringing food companies closer to the adoption of such systems, hence it is a good time to define and develop the optimum SS implementation strategy.

Keywords: Food Manufacturing, Digital hub, Sustainability Profile, Smart Systems, Survey

1. Introduction

The UK's food sector is complex and highly dynamic in nature. The demands placed upon the manufacturing system through short life products and raw materials, more demanding retailers and end users, increased levels of legislation and regulation has resulted in organisations needing to respond on multiple levels and on a range of different issues in order to achieve economic and environmental sustainability [1]. In some cases, these pressures have resulted in the sector becoming increasingly isolated from other manufacturing sectors as they deal with their own specific problems [2]. The resulting problem of this isolation is that many food manufacturing companies are not necessarily aware of the advances in manufacturing technologies and systems being developed and applied throughout the wider manufacturing industry. This in turn can lead to the creation of an environment where the food manufacturing industry may be left behind when it comes to adopting and benefitting from new and advanced manufacturing technologies [3].

Isolation of the sector, and further isolation of individual problems and symptoms at a business unit level, threatens the economic sustainability of food manufacturing companies and the sector as a whole. Major retailers offer these food manufacturing companies the greatest potential for increased sales, job creation and efficiency of production. However, this has to be reconciled with the demands of reduced profit margins and increased costs associated with higher volume requirements [4, 5].

In order to cope with these business pressures, other manufacturing and production sectors have placed increasing focus upon the development and advancement of technology driven manufacturing systems such as; Smart Factories, Smart Systems and, Industry 4.0 (I.E. 4.0). These systems are often known collectively as Smart Systems (SS). Recent years have seen step change improvements in terms of Smart Systems' capability, reduced cost of technology, and wider accessibility of the skills and knowledge required to implement them. Therefore, we can articulate a current challenge within the UK food manufacturing industry in terms of three distinct objectives aimed at overcoming their isolation and, align their businesses towards Smart Systems implementation. These objectives are:

1. Understand the current expertise and identify the technological priorities of the UK food manufacturing companies when considering the implementation of Smart Systems
2. Identify the required system capabilities with the relevant key enabling factors of the available Smart Systems
3. Create a conceptual system architecture and appropriate support infrastructure, to invest in the right tools at the right time, to achieve effective system implementation

This paper aims to tackle objective 1 directly, by qualitatively analysing both secondary and primary research data to understand the current technological and systems platforms within a sample range food manufacturing companies. Objective 2 is addressed in terms of the available smart system capabilities, identifying the technological priorities typified by companies successfully utilizing smart systems at the current level of maturity. Finally, the paper goes on to address objective 3 by developing a conceptual framework for the implementation of SS in context of the business drivers seen in the initial research to demonstrate how companies can utilize particular key enabling factors for results focused implementation.

Evidently, effective implementation is the key to success, and learning from experience in implementing other business improvement practices and paradigms shows that there is no single prescriptive implementation guide to fit every company. So, this paper takes an important early view of enablers and potential barriers to success and presents them in context of the process defining the implementation strategy, which is a framework to be easily leveraged across both the UK and international food sector in order to minimize the learning curve costs and timescales.

1.1 Sustainability and Smart Systems

The industrial trend towards the adoption of Smart Systems is based largely on the perceived positive benefits that cyber connected automated systems can bring to industry such as improved efficiency, greater customisation, improved quality and reduced waste and enhanced economic sustainability [6]. However, research is starting to emerge around how Smart Systems impact on sustainability dimensions. For instance, Bonilla et al [7] through a comprehensive literature analysis link four different business scenarios (deployment, operation and technologies, integration and compliance) with sustainable development goals. From these scenarios, their analysis resulted in the

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identification of a number of positive and negative sustainability impacts being identified when related to the basic production inputs and outputs flows (raw material, energy and information consumption and product and waste disposal).

Smart Systems (SS) can be defined as the development of manufacturing technologies to allow higher levels of interconnectivity, leading to greater communication between machines and decentralised/local processing of data [8]. SS embraces a wide range of technologies, including Radio Frequency Identification (RFID), Near Field Communication (NFC), Wi-Fi, Cellular and Bluetooth all linked to networks that normally use the Internet as a form of communication [9, 10]. SS technologies offer many benefits, including the ability to improve food traceability, reduce food waste and increase efficiencies in transport and handling of food products and therefore contributing directly to addressing the environmental sustainability challenges. On a wider scale, virtualization of supply chains using SS technologies enables companies to optimise supply chain operations and characterise the dynamic nature of operations [11]. Virtualisation also enhances the opportunity to apply innovations and improvements in supply chains and, to subsequently plan, and assess these innovations without affecting the manufacturing system. It also enables innovative thinking amongst staff and the promotion of the view of what new and innovative technologies can do to enhance productivity and product innovation [12] as well as addressing the economic sustainability challenges. Today the technology is highly reliable, relatively cheap, and based on international standards that promote easy communication between different device's tags and systems [9]. The result of the emergence and application of SS has led to the creation of Smart Systems and Smart Factories in which machinery is increasingly autonomous, so it is able to manage its own service and maintenance requirements, and, adapt instantly to new requirements. It is through the adoption of these advanced manufacturing and communications technologies and systems employed through SS that the authors believe that food and drink manufacturers could benefit from more than most other industry sectors.

Evidence suggests that the food industry is ideally placed to benefit from adopting SS [8]. The continuous demand to maintain and often reduce costs in the food industry means that companies have to continuously innovate and develop more efficient manufacturing systems as well as seeking to innovate the product in order to maintain cost levels. SS is likely to be seen as a significant opportunity for companies to potentially stabilise productivity and improve output both in terms of cost reduction and quality consistency [8]. Greater flexibility offered by Smart factories will enable product volume mix to be achieved with greater levels of consistency and efficiency. In many cases, bespoke manufacturing can be achieved as well as the capacity to rapidly change to differing customer demands as a result of such technologies and systems.

So, if the food manufacturing industry is ideally placed to take advantage of SS, then why is the industry slow to pick up on the concept and implement such systems? The traditional barriers towards the implementation of Advanced Manufacturing Technologies in the past have focused upon the high cost of technology and limited capability of the existing workforce to operate and develop the technologies [13]. However, with the emergence of relatively inexpensive internet-based technologies and systems, why are these barriers still relevant today? The starting objective of this study therefore, is to understand the challenges and barriers that limit UK food manufacturing from implementing technological systems such as SS. This is achieved by means of a two-stage survey into thirty-two UK food manufacturing companies as well as analysing the findings from industry reports

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and academic texts. From this stage of work, this paper will identify the current status and greatest opportunities for UK food manufacturing companies in terms of meeting the food sustainability challenges. The research question for this initial study is therefore: "*what are the current systems capabilities and technological priorities of the UK food manufacturing industry to meeting current and future sustainability challenges and, what are the key enabling features of Smart Systems which will improve performance of UK food manufacturing companies?*".

At this stage it is worth establishing what 'Food Manufacturing Companies (FMCs)' are in the context of this study. It can be argued that all companies involved in the production of food products can be considered food manufacturing companies. However, this leads to a highly complex view of food production and one that is difficult treat as a whole when considering specific and focussed research. In order to keep this research focussed and manageable, the authors have concentrated their research on food manufacturing companies. Food manufacturing (which incorporates food production and food processing) is primarily concerned in converting raw ingredients and products in to food products. These companies are normally identified as mass production/high volume companies and as such, is of particular interest to the authors as this is where the use of advanced production and manufacturing systems are likely to be highly applicable and useful. Therefore, this research programme focusses on the application of Smart Systems on food manufacturing companies.

2. Literature Review

UK food manufacturers are highly aware of the need to operate within highly visible supply chain systems. Smart Systems provide this essential link in that it the technologies and systems enable improved level of traceability right through the manufacturing chain where machines are interconnected and archiving data can be done automatically. Alongside this, environmental tracking can be better achieved as well as monitoring energy usage so that optimising energy consumption profiles can be achieved. In the whole, the likely result of the adoption of SS in the food manufacturing sector will result in improved machine performance, optimised maintenance and reduced costs [8]. This should then provide new opportunities for companies to win new customers and retain existing ones. It is also likely to create new revenue streams in the form of value adding services and, allow seamless connectivity with upstream and downstream supply chain partners [8]. More importantly, SS should not be seen by the industry as one that precludes the smaller food producers. If looked at more seriously, SS offers more opportunities for SME food and drink producers, in that they will be able to form seamless links with their customers and suppliers as well as being able manage smaller production volumes with increasing levels of efficiency. Adoption of SS is then likely to level the playing field between small and large food producers as their systems are likely to be just as advanced and sophisticated as each other.

Where SS is likely to pay particular dividends for food manufacturing companies is in the area of maintenance management and in the actual maintenance of equipment and systems through Cyber Physical Systems [14]. With machine systems becoming ever more sophisticated, machine self-diagnosis and fault tolerance capabilities enables companies to pinpoint system problems sometimes before they actually manifest themselves in lost production. This allows for the optimisation of preventive maintenance programmes so that expensive and delay-inducing machine failures can be designed out as best as possible. In doing so, machine downtime is reduced and machine availability and productivity will rise. So, SS will improve data management through better communication and data collection across all machines in the manufacturing chain; likewise, this data visibility will enable companies to share essential information across the supply chain in general, thus potentially increasing supply chain reliability and production availability. Instant archiving; real-time analytics; multifunction alarm management; web-publishing; as well as interconnectivity and data transparency throughout the entire value chain [15].

Through this very brief analysis of SS it is clear to see that the benefits to food manufacturing companies and food producers more generally can be significant. However, there is a concern from experts within the sector that the principles of SS are not understood by the food manufacturing companies whilst they continually flag up the need for more sophisticated and advanced systems of operation. This is of major concern to the future economic sustainability of UK food manufacturers and threatens the reliability of food manufacturing as a result of not embracing the key issues of SS. Food and drink manufacturers are already experiencing a wide range of demands from customers including: healthy and eco-friendly packaging; extended shelf life of products achieved through modified atmosphere packaging as well as supermarket house brands completing with mainstream brands. However, the industry's greatest challenge (as well as opportunity) is the adoption of SS [16].

As mentioned previously, SS can be considered as the digitization of manufacturing and the increasing digital connectivity of product, process, and factory. It refers to the development of smart factories in which new manufacturing technologies allow for greater communication between machines, and machine-level processing of data allows them to adapt instantly to new manufacturing requirements. It also refers to the connecting of information systems and sharing of data across the supply chain to improve efficiency [16]. As a result of the adoption of SS, food companies will need to focus on a different knowledge skillset and, will therefore need to recruit, upskill, and keep staff capable of maintaining these highly complicated business operations. The development and retention of these highly skilled people will be critical since the costs of production-line downtime will increase exponentially, and it will be imperative to have staff on hand who can instantly troubleshoot system faults and get machinery up and running quickly as well as being able to manage the effective synchronisation of logistics systems with manufacturing operations. The cost of training will therefore be seen as negligible when compared to the loss of manufacturing capacity and production downtime as a result of failure of this digitally connected factory [17].

This paper has already highlighted some of the traditional barriers and issues that food companies put forward as a reason for not investing in new and advanced technologies. However, further evidence suggests that UK Food companies may not be fully aware of the benefits that SS can bring. In 2016 the Food Manufacture Group conducted its inaugural Supply chain and logistics survey on its user base of UK food and drink manufacturing professionals [18]. The aim of the survey was to gauge views on changing food and drink supply chain priorities, from the use of outsourced logistics and warehousing to the biggest supply chain challenges and changing customer needs. The survey collated over 220 survey responses on topics such as costs per case, biggest supply chain challenges, challenges in investment etc. The results highlighted that in the majority of companies, their company's supply chain cost per case/pallet delivered had increased over the past year. The top three biggest supply chain challenges were: on-time, in-full deliveries; cost reduction per case/pallet delivered and, relationship with retail customers. The survey respondents also confirmed that these challenges will be a focus of investment for their companies in the coming months.

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Alongside these challenges, these supply chain companies also highlighted that their top three supply chain needs were; reduction in lead-times, product and ingredient traceability and price reduction. On the other hand, reduction in packaging and increased IT integration were the least important needs to our respondents. However, some 76% of their survey respondents agreed that their companies were increasing efforts to work more collaboratively with their customers/suppliers. Interestingly, this survey points to a somewhat complex and confusing picture of 'wants and needs' within the industry in which the means of obtaining greater collaboration and improved productivity as well as reduced production and raw material costs is unlikely to be achieved through greater use of IT systems integration. In fact, the adoption of new and advanced IT systems as well as the need for agile and responsive manufacturing systems fared poorly when compared to the need to reduce production costs and increase productive efficiency. The survey data therefore suggests to some extent that the demand for SS is not yet seen as a major business enabler for the food manufacturing industry.

Furthermore, the annual "state of the UK food and drink sector survey" [19] surveyed 510 UK food and drink manufacturing professionals. The focus was on gauging the views about the current state of the industry highlighted some key issues and concerns. Survey responses on topics such as market conditions, Brexit, trading relationships, environmental management, investment and employment, and product development from industry professionals highlighted that the majority of companies maintained a positive outlook and saw a long-term future for the UK food manufacturing industry. Some 60% of the companies surveyed voiced their concerns that Brexit would be bad for their businesses. The survey respondents also highlighted that pricing pressures from retailers as well as increasing raw material costs continued to threaten to commoditise branded products and cut into resources devoted to NPD and innovation. However, while the surveyed respondents identified a need for maintaining a low-cost base as well as the need to innovate through new product development, they did not identify the need for investment in systems such as SS and improved integration of communication systems through the supply chain. Again, this suggests that UK food and drink companies are not fully aware of the issues and capabilities of SS.

It therefore seems that the food industry in general, lacks the knowledge and understanding of the need to implement new and sometimes advanced technologies in to their business. This issue is not necessarily restricted to UK manufacturing companies. The Technology Industry Report [20] identified the preparedness of a range of manufacturing companies in the USA and stated that 88% of manufacturing industry executives identified that SS would increase company competitiveness with 75% of executives identifying automated technologies as being critical to becoming competitive and over 64% of executives believing that SS was essential to becoming and/or remaining competitive. However, when the survey asked whether the companies were prepared or preparing themselves for the introduction of SS nearly 55% of companies identified cost as being an issue that was preventing the implementation of Smart Systems. Also, some 47% of staff were reluctant to change and, 46% of executives believed that their employees lacked the skills and knowledge to implement and develop SS in their companies.

The lack of uptake of new and advanced manufacturing technologies is not necessarily just a food industry issue. Similarly, a European Commission survey [13] of over 600 manufacturing companies (both large and small) throughout Europe aimed at identifying the barriers and drivers towards the implementation of Advanced Manufacturing Technologies (AMT) (including Smart

Systems and I.E 4.0) identified that there was a strong need to accelerate AMT uptake, in particular amongst manufacturing SMEs. It identified that the spread of AMT had remained too focused on specific countries and certain sectors to spur meaningful, broad-based industrial modernisation across the continent. In particular, this holds true with respect to complex technologies but even with respect to basic capabilities more needs to be done. The report also identified that the main drivers for investing in AMT were found to be largely internal, resulting from a combination of commercial and technological considerations: reducing manufacturing costs, improving the quality of products and services, improving the firms' employees' productivity and the reduction of production lead time. The barriers to investing in AMT, in contrast, are made up by a mix of internal and external factors. For nearly three quarters of the firms, the most important barrier is the high cost of investment in AMT acquisition and the lack of financial resources. Moreover, about half of all firms indicate difficulties in assessing the performance and the potential business return of such technologies and/or the lack of skilled personnel required to adopt and adapt relevant AMT. These findings from a general survey of manufacturing companies offers similar findings to those seen by food producers.

The PWC survey [21] of over 2000 respondents from a wide range of industries across the world identified that there was a distinct appetite for moving towards taking real action in starting to implement I.E 4.0 and to move away from talk to action. The survey of business and manufacturing leaders identified a number of key enablers required to kick start I.E 4.0 implementation including: focussing on people empowerment, training and, the cultural change required to provide the infrastructure to undertake the transition process; the need to develop strong horizontal collaborations and effective networks of customers and suppliers where digital systems are able to play a key role in managing the network functions. This may be particularly problematic for the food industry where, as reported previously, the isolated nature of food companies means that they are more likely to remain with small range of tried and trusted suppliers and customers where the likelihood is that these companies would not necessarily see the need for such a digital framework. However, with a change in culture will come a change in vision and confidence and as a result, food producers may find the adoption of I.E 4.0 and Smart Systems the key to developing wider and more comprehensive collaborative networks.

In summary, the benefits that SS can bring are appreciated by many industrialists and academic alike. Improved product traceability, (including traceability in the food recall system, [22]. Productivity throughput, shorter processing times and improved consistency of product quality are all seen as positive elements of SS implementation. However, the barriers around technology cost, workers skills etc are still seen as key barriers by the sector. The falling cost of technologies as well as the ubiquitous nature of internet connectivity combined with relatively powerful computing equipment raises the question as to whether the traditional impediments of technology cost and worker skills are still seen as major barriers or, whether these issues remain perceptions based on a previous era of manufacturing. Evidence suggests that many companies are not fully aware of the concepts of SS and as such, may not be fully conversant with the systems in order to make an accurate judgement on whether their benefits would outweigh the limitations and the views that they traditionally hold. In order to further understand this issue, the authors undertook a small-scale survey of thirty-two UK food manufacturing companies of various sizes with the aim of identifying the level of awareness of SS within their companies and to also identify the dynamics around technology adoption in these companies is changing. Although the survey is small scale and hence

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does not allow for wider generalisation of the results, the authors undertook the survey to identify some baseline information of how industry leaders are viewing technology adoption in their companies. The information of the survey is shown in the next section.

3. Research Method and Survey Design

A triangulated research approach was employed consisting of the following stages:

1. Analysis of secondary research obtained from governmental and trade reports as well as research undertaken by academics and industry fora.
2. A small-scale pilot survey of food manufacturing companies (stage 1 research study).
3. Follow-up interviews with MDs and Managers from the small-scale pilot study (stage 2 research study).

Analysis of the extant literature in this area identified a number of barriers and inhibitors to the application and implementation of SS. Some traditional barriers such as cost etc were identified. However, training and human competency development was also seen as key limiters to implementation. Human competence extended not just to the knowledge required to implement and operate such system but also, to the general understanding of how SS is able to improve the strategic and manufacturing capabilities of a company. In order to verify the secondary data findings, a two-stage research survey consisting of a high-level sustainability profiling analysis of thirty-two food manufacturing companies followed by a deeper level interviews and company visits in to twenty food of these companies enabled the research team to obtain a deeper understanding of the issues surrounding SS implementation.

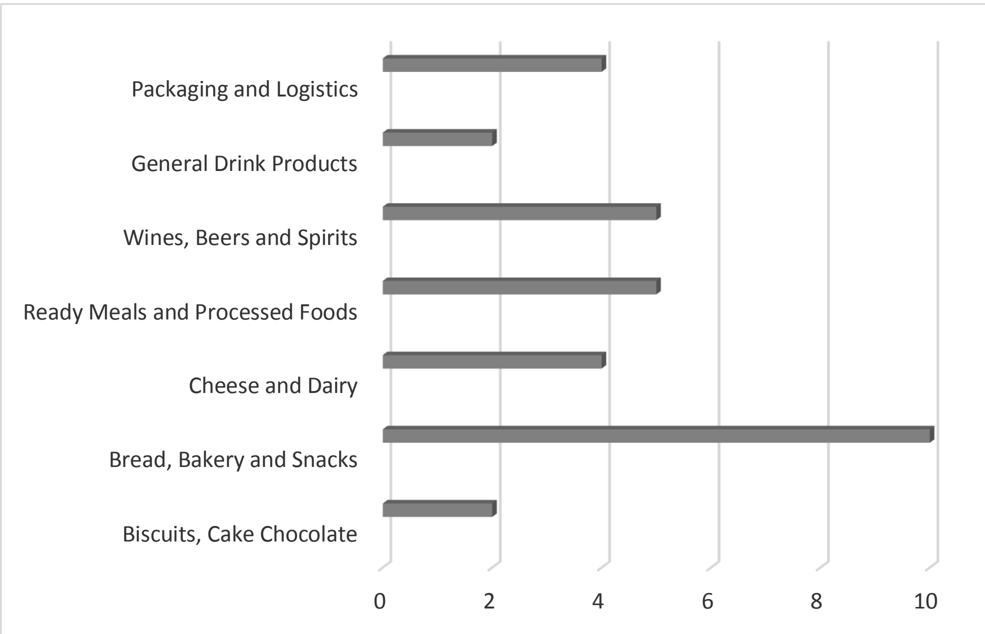

Figure 1 – Sectors Responding to Survey

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The initial stage of the stage one research process was to develop an appropriate measuring tool that could be used to measure specific responses from the companies but also to act as a point of reference for discussion around SS implementation. The authors developed a sustainability profiling tool based on the work of a range of academics [23-27]. Through a comprehensive study of the key sustainability challenges facing UK manufacturing industry, a profiling tool was developed that identified the key strategic drivers but also identified the technological areas that are required for implementation. The profiling tool is shown in Table 1. The tool highlights the key sustainability drivers that impact on both economic and environmental sustainability. Furthermore, the tool also proposes the key SS technologies and systems needed to support the sustainability drivers. The drivers are further segmented between economic and environmental drivers (or both).

Companies were selected by the research team based on the definition of a food manufacturing company provided earlier in the paper, that of: *being primarily concerned in converting raw ingredients and products in to food products and, identified as mass production/high volume companies employing high volume manufacturing systems and configuration*s [19]. One hundred and thirty requests were issued electronically to food manufacturing companies asking the M.Ds of each company to take part in the survey. Thirty-two companies responded agreeing to undertake the survey. Whilst this level of response was disappointing, the thirty-two company responses did provide the team with sufficient information to at least validate the findings from the secondary research phase. Figure 1 shows the sectors which responded to the survey. In terms of company size (measured through number of employees in the companies), 18 responding companies employed 10-50 employees, 10 employed 50-150 and, 4 responding companies employed between 150-200 employees.

During the profiling stage, each company was contacted and, a time arranged for a member of the research team to visit the company. The initial stage of the study involved a member of the research team meeting with the MD of each company to discuss the sustainability profiling. The profiling stage involved a discussion about each strategic driver, explaining what each of the drivers and associated technologies meant in order to ensure that there was a common understanding about the meaning of each driver. The research member in discussion with the MD then completed the profiling exercise. Scores were placed against each strategic driver and associated indicative technology. The first stage was to score the current level of capability and capacity of each company against the eighteen variables. The second stage of scoring required the MD of each company to prioritise each driver and technology identifying where they wanted to see their companies in two years. This profiling allowed the team to determine the current state of operational excellence and, also the aspirations of the company in meeting the SS requirements. The gap between current state and the aspirational level 2 years in to the future provides the basis of discussion in stage 2 of the research study. The researcher also observed the work being undertaken on the shop floor and, assessment of the technologies and systems employed. This enabled the researcher to validate the scores provided by the M.D/senior manager for each company.

4. Results of the Sustainability Profiling Stage

A synopsis of the stage 1 sustainability profiling results is shown in this section of work. Table 1 shows an average score of the thirty-two food manufacturing companies on their assessment of their current technological expertise and also, their two-year technology priority score. Furthermore, the table also shows a frequency analysis which profiles the score each company provided against each

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technology area. This enabled the researchers to understand the relative level of expertise each company had in relation to the technology areas. For instance, technology area V3 showed that with the exception of one company, all the other companies believed that they were very good or excellent in developing robust new product development processes whereas area V8 which scored a similar average score, showed a wider spread of responses ranging from good to excellent. Figure 2 focusses specifically upon the sample group's average current technology expertise / capability in ranked order. Taking the top four criteria from this figure shows that; the companies new product development and introduction capabilities along with their customer integration, waste reduction and, technology management expertise was considered strong and well developed. Where the companies scored less well were in the lower four criteria namely; university and knowledge base collaboration, organisational learning, digital connectedness and, data analytics. Figure 3 shows the average two-year priority scores offered by the sample group of companies in ranked order. The two-year priority score is a measure of what the companies considered as the key technologies and systems that need to be in place in order for the companies to remain competitive over the medium strategic planning horizon. The figure shows that the top four priority areas to focus on are: energy neutral production systems; information sharing systems; digitally connected supply chains and, rapid reconfigurable supply chains. The four criteria of least concern are; university and knowledge base collaboration, customer and supplier collaboration, intelligent decision making and, competency management.

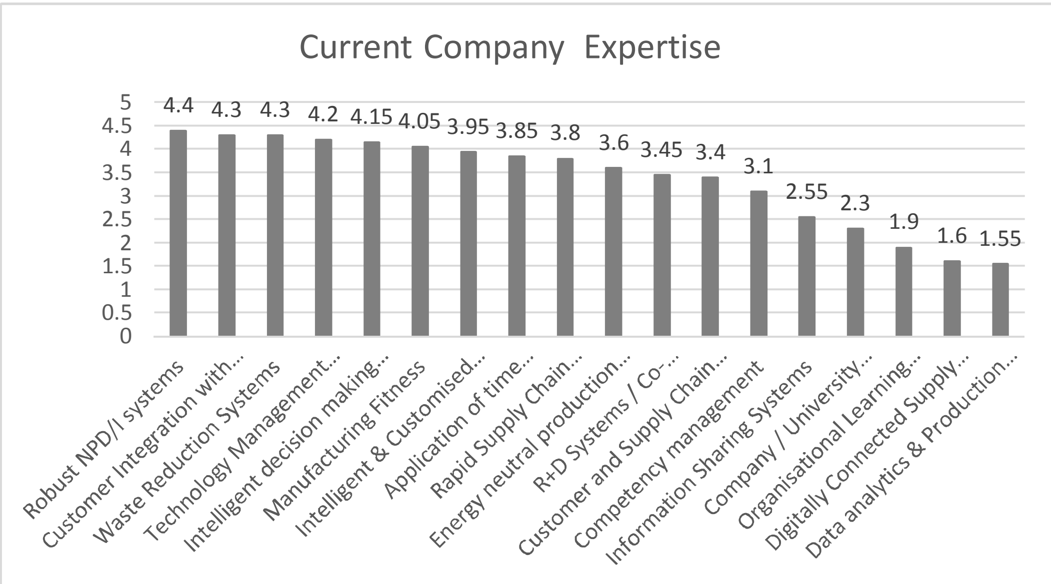

Figure 2 – Current Expertise in Ranked Order

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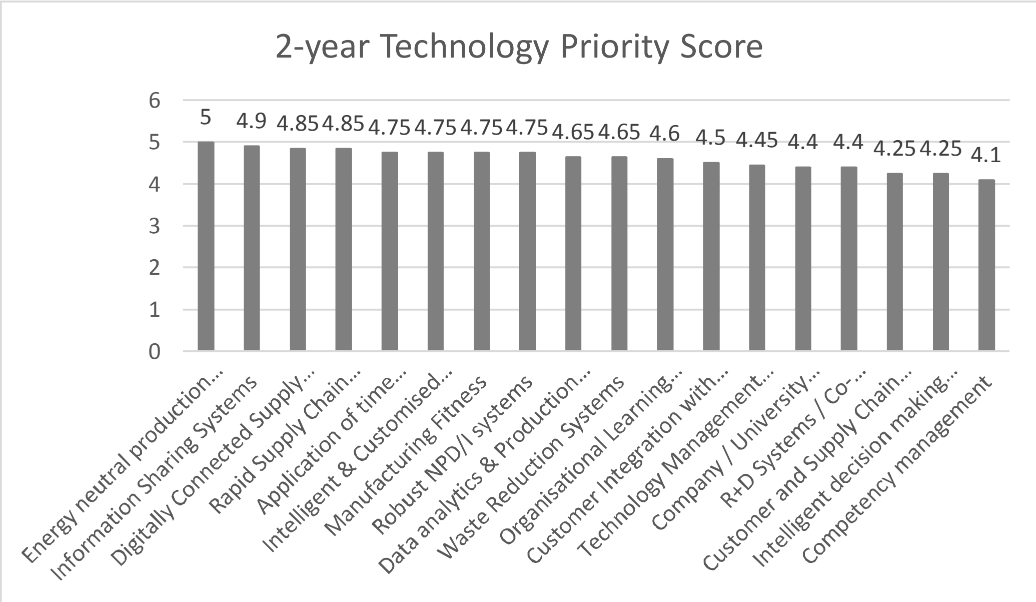

Figure 3 – Two Year Technology Priority Score in Ranked Order

Figure 4 shows the analysis of the sample group's current capabilities against their two- year technology priorities. When analyzing this data, areas of particular importance within the figure are the criteria in which there is a significant difference seen between current and future technological priorities. In this case, the top four features that show the greatest gap between current expertise and future requirements are: digitally connected supply chains, data analytics and organizational learning capabilities and, company and University collaboration.

4.1 Analysis of Results

The findings of the current expertise analysis (Figure 2) was unsurprising. Food manufacturing companies have traditionally developed strong NPD/I systems that involve close collaboration with customers. Likewise, the management of their current manufacturing systems and technologies as well as developing robust waste reduction systems is well known. Likewise, areas that receive less attention such as collaboration with knowledge bases and lack of understanding of digital connectivity and data analytics is also well known within the industry. Therefore, the common issues found within the wider food manufacturing industry are accurately reflected within this smaller sample group.

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Table 1 – Sustainability Profiling Input Sheet

Sustainability Drivers	Technology Areas	Average Current Level of Expertise	Average 2 Yr Priority Score	Gap	Frequency (Current Expertise)				
					1	**2**	**3**	**4**	**5**
Time to Market (Ec)	V1 Customer Integration with product development process	4.3	4.75	**0.5**	0	1	2	15	14
	V2 Application of time compression technologies	3.85	4.5	**0.7**	0	1	11	12	8
Product Innovation (Ec)	V3 Robust NPD/I systems	4.4	4.65	**0.3**	0	0	1	16	15
	V4 Intelligent & Customised products	3.95	4.45	**0.5**	0	2	8	12	10
Human Competencies (Ec/En)	V5 R+D Systems / Co-Innovation/creativity	3.45	4.25	**0.8**	3	4	8	9	8
	V6 Competency management	3.1	4.75	**1.7**	5	6	7	7	7
Knowledge Management (Ec/En)	V7 Organisational Learning systems	1.9	4.75	**2.9**	14	10	5	3	0
	V8 Intelligent decision making systems	4.15	4.75	**0.6**	0	0	8	12	12
Energy Neutral Systems (En)	V9 Waste Reduction Systems	4.3	4.85	**0.6**	0	0	3	17	12
	V10 Energy neutral production systems	3.6	5	**1.4**	3	2	8	11	8
Enterprise Reconfiguration (Ec/En)	V11 Information Sharing Systems	2.55	4.4	**1.9**	8	9	7	5	3
	V12 Rapid Supply Chain Reconfiguration	3.8	4.25	**0.5**	0	2	11	11	8
Collaborative Networks (Ec/En)	V13 Customer and Supply Chain Collaboration	3.4	4.1	**0.7**	2	6	8	9	7
	V14 Company / University Collaboration	2.3	4.9	**2.6**	7	14	8	2	1
Management Paradigms (Ec/En)	V15 Manufacturing Fitness	4.05	4.4	**0.4**	0	0	9	13	10
	V16 Technology Management Systems	4.2	4.6	**0.4**	0	0	5	16	11
Digital Systems & Technologies (Ec/En)	V17 Digitally Connected Supply Chains	1.6	4.85	**3.3**	16	13	2	1	0
	V18 Data analytics & Production Analytics	1.55	4.65	**3.1**	16	15	1	0	0
Key: Ec = Economic Sustainability Driver, En = Environmental Sustainability Driver, Ec / En = both.									

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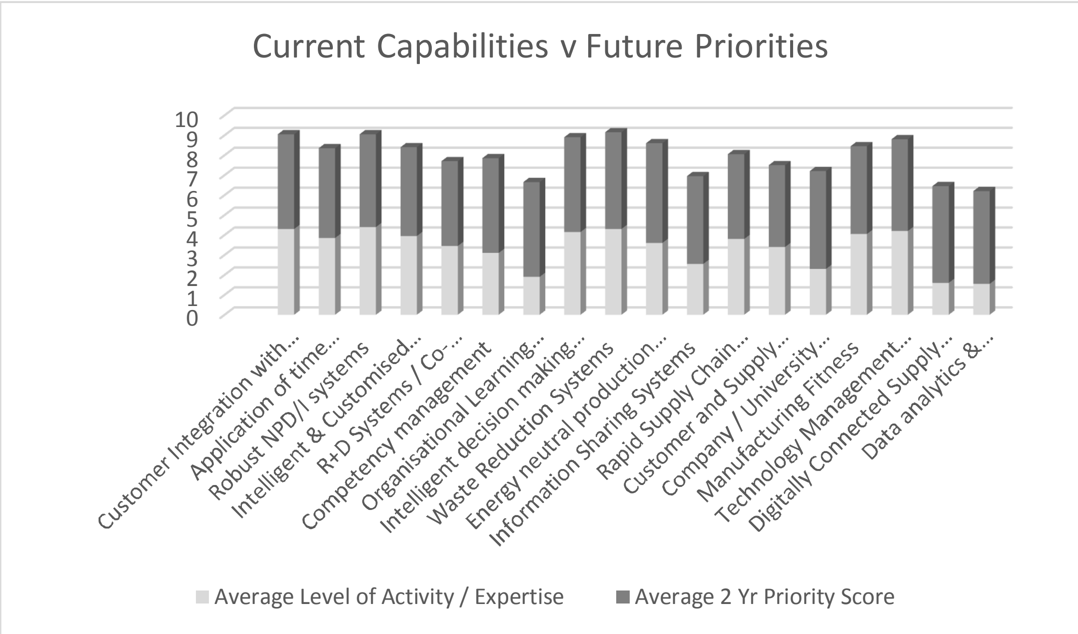

Figure 4 – Analysis of Current Technology Capabilities versus Future Technological Priorities

Analysis of the two-year technology priorities showed that companies were very aspirational in implementing and developing state of the art technologies and systems. In particular, the focus on reducing energy consumption and moving towards energy neutral manufacturing systems is interesting since previously, companies felt that their waste reduction strategies were relatively well advanced but their energy reduction strategies needed further work and development. Of further interest was the identification of the priority to have 'digitally connected supply chains'. So, although seen as a strategic priority, the companies did not see themselves having the current expertise to move towards this priority area. Technological areas seen as being less of a priority still included University/ knowledge base collaboration and the more general issues around Knowledge Management. Therefore, although the companies showed high aspiration towards the implementation of Smart Systems technologies, they did not consider knowledge management and collaboration as being key areas for future development.

Figures 4 & 5 shows the gap analysis undertaken on the results provided. They both identify four clear areas where a significant gap between current expertise and technology development priorities lie. Most concerning here is that there seems to be little understanding amongst the surveyed companies that in order to move to the adoption of Smart Systems, there needs to be greater development of staff and, further collaboration with Smart Systems experts that are very likely to exist outside the food industry. Therefore, it is likely that the industry will need further guidance, support and a structured approach towards moving towards SS implementation. The remaining sections of this paper will highlight some of the key SS technologies and systems as well as develop a conceptual framework for the industry. However, before this, the authors needed to understand further the deeper underlying issues around the disparities found between the strategic intent of the companies and, the strategic priorities the companies had highlighted.

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4.2 Stage 2 Interviews

Following the profiling exercise, the researchers moved to the second stage of the study. The Managing Directors and Senior Management of twenty companies from the original survey group agreed to be interviewed further through unstructured face-to-face interviews. The aim of these interviews was to discuss further the responses provided and shown in Figure 5 of the previous stage study and, to understand the complex nature of the priority areas highlighted by the surveyed food manufacturing companies.

During this research phase, the interviewees identified primarily that SS would provide is greater resilience and improved levels of economic sustainability. These strategic level opportunities were seen as the top priority of all participants interviewed. Stemming from these strategic level opportunities were the operational and environmental opportunities that acted as antecedents to the major strategic driver of economic sustainability (i.e. greater operational efficiency, leaner production systems, reduced waste and improved energy usage). When discussing the barriers and limitations to SS implementation, the companies highlighted their lack of readiness and preparedness to adopt SS and, questioned whether SS would be effective in their organisations. Most participants identified the nervousness of moving in to SS implementation due to the relative immaturity of the technology and, the lack of examples of successful implementation and operation of such systems within their industry which led to the concern as to whether SS was a long-term viable opportunity in which to invest. Muller et al [27] in their large scale survey in to identifying the opportunities and challenges of Industry 4.0 in 746 German manufacturing companies found very similar issues to this study and concluded that whilst I.E 4.0 is often seen as a panacea for productivity, its success in implementation and subsequent use is down to the correct fit between company characteristics and the technologies and systems employed.

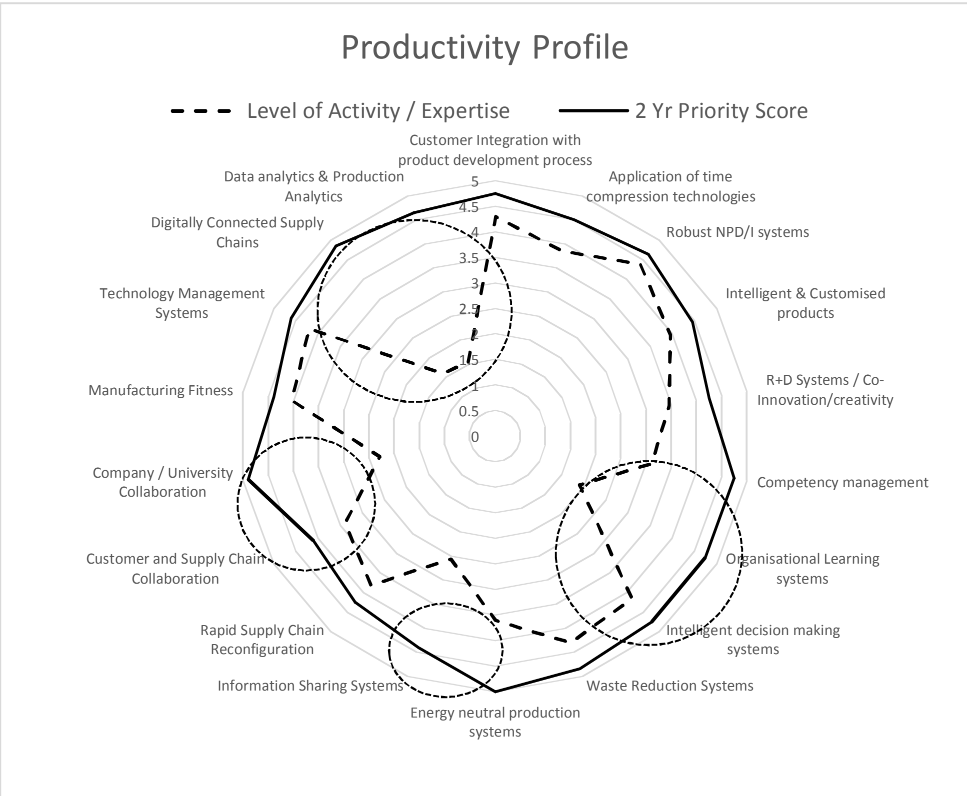

Figure 5 – Sustainability Profile

It was felt that this would result in a worker premium having to be paid on the remaining workers thus impacting negatively on product cost. Most companies had gone through the pain of training and developing local workers but had largely failed to retain the local workforce. The potential quality problems emanating from the need to employ new staff was also seen as a potential future concern. Therefore, with the potential need to employ new and inexperienced staff in a post-Brexit era, company directors now saw the switch to SS and its associated technologies more realistic and possible considering that they felt that a seismic change in company strategy was needed soon. Therefore, all the companies interviewed were planning to introduce new and more sophisticated technologies in order to combat the potential scarcity and uncertainty of human resources. However, it should be noted that very few of the companies knew anything of the principles of SS and were focussed upon using automation to replace workers as a solution to a problem rather than a focussed drive to integrate technologies with internet capabilities. Companies in general also felt that through the adoption of SS, the image of the industry could be improved towards being one that was more sophisticated in nature and more exciting to work within. It was felt that the 'knock-on' effect to this image change would be that more talented workers would be drawn to the industry thus reducing the concerns over attracting talent in to the industry.

Furthermore, the primary focus of development within companies was on manufacturing performance whereas most companies were much more comfortable with New Product Development and innovation through product development. Rather, they saw *process innovation* as being a key driver for growth with their focus on the continuous improvement of manufacturing capacity and capability. This was primarily down to the issue that the companies surveyed were mainly food processors and had little responsibility for product development. Most MDs saw this as a major concern for future sustainability and believed that having responsibility for new product development would enable the company to have longer term viability.

5. Future Directions for the Industry (Key Enabling Features)

The second objective of this study was to *identify the required system capabilities with the relevant key enabling factors of the available Smart Systems.* Its purpose is to overcome the sector isolation and, move towards providing the food manufacturing sector with a greater understanding of the utility of Smart Systems. Information contained in this section of work was obtained from the research methodology outlined previously in this text. Information was also obtained from secondary data sources (journal & conference articles, industry reports) as well as interviews held with academics and industry leaders. This information provided the authors with some key enabling features that will set the strategic direction for UK food manufacturing companies.

For change to occur in any environment, there must be an external force or forces that will play an important part in driving such change. It is likely that in order to reduce production costs and to increase production yield, food production systems will need to acquire a greater level of automation [28]. In the future, 'lights out manufacture' and 24:7 manufacturing will rely heavily on automated systems and technologies. Many large-scale manufacturing facilities already operate using partially automated systems, but it will require a shift towards web based, integrated and automated systems which will ensure productive yield in increased and product quality becomes consistent and repeatable. Typical Key Enabling Features (technologies and systems) that will assist in the food manufacturing industries to move forward towards Industry 4.0 implementation include:

Big data and knowledge based automation: This will be important in the on-going automation of many tasks that formerly required people. In addition, the volume and detail of information captured by businesses and the rise of multimedia, social media [29] and the Smart Systems will fuel future increases in data, allowing firms to understand customer preferences and personalise products.

Smart Systems: There is potential for major impacts in terms of business optimisation, resource management and, energy minimisation throughout the supply chain. In food manufacturing environments, virtually everything is expected to be connected via central networks through ICT systems that allow for greater visibility across the whole supply chain and actively integrates manufacturing facilities with other supply chain companies so that food traceability can be monitored will be key for all companies. Technology in some form or another will be essential to all food companies regardless of size and shape [30,10].

Advanced and autonomous robotics: Advances are likely to make many routine food manufacturing operations obsolete, including food preparation and cleaning activities. Autonomous and near-autonomous vehicles will boost the development of computer vision, sensors including GPS, and remote-control algorithms [31].

Cloud computing Computerised food manufacturing execution systems: will work increasingly in real time to enable the control of multiple elements of the food manufacturing process. Opportunities will be created for enhanced productivity, supply chain management, collaboration, resource and material planning and customer relationship management [32]. The degree of automation and autonomy of the food manufacturing systems utilising emerging technologies and creating more productivity and efficiency [28] is likely to move the industry further to a fully automated manufacturing environment [33].

New management approaches for Smart Systems: The demands around ensuring security and reliability of food availability requires serious changes in the way food manufacturing functions are managed. Improving distribution, increasing productivity, and reducing waste though a range of initiatives such as enhancing food supply, better network planning of outlets and distribution to maximise efficiency and improve resilience, utilisation of new materials and biomaterial processing, multiple use of crops/waste streams and novel processes to minimise water and energy requirements, are all key issues requiring new management paradigms to effective manage the complexity of such systems [34]. Managing Smart Systems through Cloud management, Big Data Analytics and intelligent decision-making systems [35].

New skills and Knowledge Bases: Smart Systems will require workers to gain knowledge that will enable the development of "digital thinking" so that they may manage the process in a new way. Those who do not will be able to read the data, analyze them, and determine their nature independently but will be slower than competitors. Employees will also require more autonomy and be allowed independent decision making [36,37].

Whist many of these technologies and systems will be focussed upon the large food manufacturing companies and secondary production providers (such as packaging, logistics and warehousing etc), more elementary yet critical technologies and systems are required by the small food suppliers such as the micro SME and SME. Specifically, the following key technological areas are required in particular (not exclusively) by smaller companies. Developing a sound knowledge around digital marketing and e-Word of Mouth (e-WoM) [38-40] [22] in order to ensure that smaller companies achieve greater visibility with a wider range of customers. Connected to this would be the

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use of an 'Advisor' website which would enable customers to rate the company's quality of service and product [41]. Allied to the above, the enhancement of the company's use of Social Media systems that are so designed as to catapult the company forward. This would include correct website development with enhanced capabilities around order making, payments and special product requests. Key to the enhancement of SME capabilities in the need to establish strong strategic alliances with other companies (food or otherwise) to reduce costs of shipping and logistics for instance. Using other company logistics provision in order to sell one-off products and services which would be otherwise prohibitive to do by the SME. Therefore, a mixed mode strategy is required that focuses upon the development of high technology marketing systems for SMEs and Micro-companies whereas, a more focussed high technology automated system approach is required more for the larger manufacturing facilities.

SS can create many opportunities for companies both large and small. Many barriers can exist that prevent companies from adopting such technologies. The usual limitations around cost, worker skills and knowledge are standard impediments that can be dealt with through suitable support mechanisms but it is likely to take time to achieve. SS should not be the realm of the larger companies only. SMEs have the opportunity to adopt internet based and Smart technologies thus enabling them to continue to operate in this increasingly pressurized environment.

5.1 Aligning Business Drivers with Smart System Capabilities

The features described above have been explored in depth by the authors referenced but, is it useful at this point to bring these together in terms of the wider framework of smart system benefits. Therefore, this section of the paper addresses the third objective of the paper, that of *Create a conceptual system architecture and appropriate support infrastructure, to invest in the right tools at the right time, to achieve effective system implementation.* As a reminder, the aim of this paper is not to re-define smart systems, so an existing framework was sought which encompasses a wide enough scope of smart system requirements and benefits. McKinsey & Company's "digital compass" [24] does exactly this, aligning eight basic value drivers and 26 practical Industry 4.0 levers.

It is interesting to note that this figure can be roughly divided into two sections; more 'responsive' drivers and enablers which can be described as broadly operations based and delivering principally internally focused benefit, and 'proactive' drivers and enablers which are broadly externally focused on aligning capabilities with customers' needs. These segments of the digital compass are a close fit with the food manufacturing companies business challenges respectively, as highlighted in the survey work of this study. As discussed in the results section, the perceived preference and focus of the companies on process and operational improvements will lead them to the right-hand side of the compass, while companies need to maintain market agility and responsiveness to new opportunities directs them towards left of the compass. Clearly, the two are not mutually exclusive, and management teams will often desire a mix-and- match model, but this work clearly shows that by clarifying the future vison, companies can zoom-in on appropriate segments of smart system utilization rather than be forced into an expensive "across the board" business transformation. At the outset of this work it was acknowledged there is no single prescriptive guide or model to direct business leaders toward an implementation model that will meet their exact requirements in the shortest possible time and smallest implementation cost.

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But it is an important step in creating any implementation strategy to recognize known standards and system capabilities to deliver required benefits. In addition, the results of the survey, especially the stage 2 interviews, reveal that the challenges around attraction and retention of human resources with the specialist skills required are common to both categories of company. This suggests a similar starting point for smart system implementation strategies, which then diverge according to the relevant mix and match of drivers, and implementation levers, selected from around the digital compass. Fine tuning the model for strategy selection requires further work to dissect the skills and system architecture required according to the levers to be employed, but this is very achievable in this specific sector where regulatory requirements and common process steps have driven some level of standard capability (and in turn the aspect of isolation that is hindering ongoing development). This phase of analysis also highlights the importance of creating a decision point to drive strategy formulation and focus on both specific benefit, and core competencies, for effective smart system implementation. Achieving this focus will help overcome the industry's perception of implementation costs and skill development.

Figure 6 – McKinsey's digital compass.

5.2 Implementing Smart Systems

Implementing an effective strategy requires an alignment of all the variables explored in this study. This third and final phase to the study recognises that, as in any process, the strategy definition process can be simply shown in terms of the inputs, outputs and controls that effect the process itself: This paper has considered these variables, with a view to identifying the greatest opportunity for food producers to exploit the potential of smart systems. By engaging with the initial thirty-two companies food manufacturing companies, business drivers were well articulated and split between internal and external forces. Then the academic and vocational data sources were examined to understand the key enabling factors, the core supply chain requirements and the traditional improvement paradigms such as lean manufacturing and how they are used to drive traditional productivity gains. Finally, the split between proactive and responsive improvement levers utilized by smart systems has been considered, especially with regard to the projected benefits. Figure 4 shows a schematic of the SS implementation framework. The diagram shows the required inputs in to the system. These consist of enablers, drivers, factors and capabilities that are needed for the correct implementation of the SS strategy. The resulting outputs of the framework show the proactive and response levers that lead to improved business performance. The following section details the drivers, inputs and outputs of the framework.

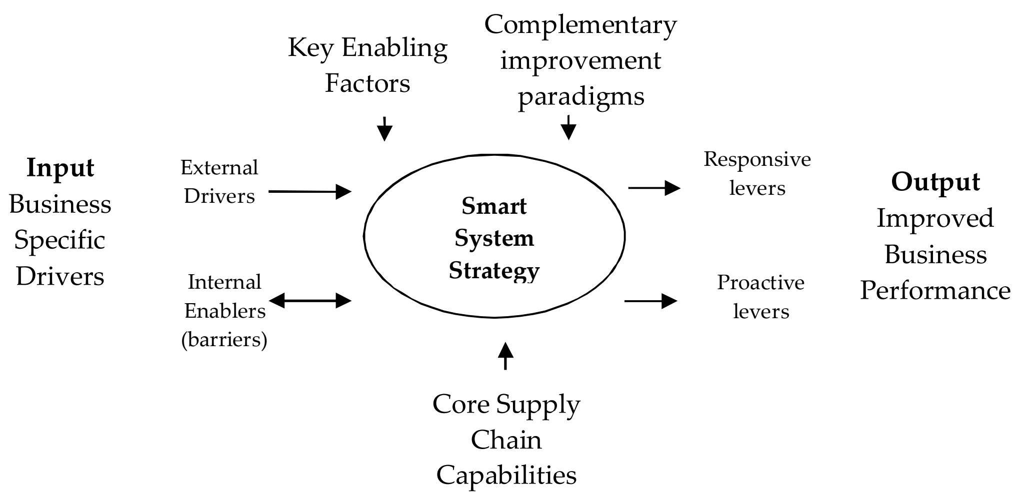

Figure 7 – Schematic of the Smart Systems Implementation Framework

Business drivers (INPUTS) :

- External drivers including environmental factors such as such as Brexit and the ensuing changing workforce demographics, as well as the ongoing trends in customer requirements.
- Internal enablers (barriers) which are traditionally understood in terms such as attraction and retention of staff, training in requisite skills, and system implementation costs.

Key enabling factors (CONTROLS) :

- Big data and knowledge based automation; (2) Smart Systems; (3) Advanced Robotics; (4) Cloud based systems; (5) new management paradigms and, (6) new skills and knowledge bases.

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- Supporting best practices such as Lean, Agility and six sigma improvement paradigms drive both the improvement culture and affect the human factors underlying many of the perceived HR related issues.

Development of core supply chain capabilities (CONTROLS) :

- virtual enterprises, digital marketing and, virtual supply chain environments focusing upon ICT and web technologies by partnering/outsourcing companies [42].
- Increase the transparency of operations through to the supply chain in order to achieve greater food security and reliability [43].
- Sustainability / resource efficiency: resource and energy efficiency, waste management, recycling [26].
- ICT - Networked business processes. Implementing technologies to share design information, and product development information.
- Cyber security systems and the security of food product and process data to ensure UK food companies protect their product data [44].

Proactive / outwardly facing smart system levers (OUTPUTS) :

- Innovation tools, marketing tools and a capability to exploit new opportunities in high-value added products or niche-market products as a strategy for growth [8].
- ICT capability to share information particularly design through product life cycle; which will help customers to access this data before any purchase commitments [45].
- Open collaboration activities between food companies operating in a trusted and truly collaborative environment will be key to developing and sustaining food manufacturing systems especially in small food manufacturing companies [46].

Responsive / inwardly facing smart system levers (OUTPUTS) :

- Rapid configuration of food manufacturing systems to be able to ramp up production or, reduce productive capacity where required. This will not only need flexible manufacturing systems but also flexible working contracts and people. High volume, low variety versus low volume, higher variety will be the likely feature of food producers in the UK [47].
- Technology developments for automation, process control, flexible machine control and, enhancing safety aspects in food manufacturing including, new manufacturing technologies, integration of technologies, novel structures and techniques [48].

6. Conclusions and Future Direction of the UK Food Manufacturing Companies

Food Manufacturing Companies in the UK face many opportunities to grow and develop. The landscape painted by these companies matches consumer trends (low cost, high volume, low variety manufacturing versus higher cost, lower volume, higher variety products and facilities). Therefore, a one size fits all strategy for supporting such companies is going to be largely ineffective and costly [27]. However, within the high-volume food manufacturing environments there is much that can be done to improve business performance. Academics and industry representatives are largely of the opinion that food manufacturing facilities lag behind other sectors such as automotive and white goods manufacturing. However, the uniqueness of the industry should not be an excuse for maintaining the status quo when it comes to seeking advancements and improvements in manufacturing. Likewise, smaller food producers should also seek new and innovative ways of increasing market visibility and seek to invest in new technologies to achieve their aim. Adopting standard manufacturing improvement strategies that are used and adapted effectively in other sectors is key to achieving change.

From a theoretical viewpoint, this study contributes to the literature on the emerging relationship between UK food companies and their motivations towards implementing SS and its connection to the dimensions of sustainable production by contrasting the effect of the external and internal pressures and drivers in FMCs. More specifically, the work provides for a more qualitative understanding and clarification with regard to opportunities and challenges that are considered relevant for SS implementation and value creation within the food production industry. Further, this paper adds to the limited body of literature in to investigating the dimensions of sustainability by highlighting that strategic opportunities are main drivers for the implementation of SS in FMCs with operational and environmental opportunities being considered as the secondary drivers. This study, has provided an interesting additional dimension to the study undertaken by Muller et al [27] where similar outputs emerged from a large scale quantitative study in to a range of German industries. This paper therefore provides an additional set of dimensions specifically from the food sector which helps to build a richer picture of the issues in the implementation of SS.

In this study, the issue of a company's preparedness for SS was examined based on both external and internal drivers. The study showed that external drivers are currently more important than internal drivers in moving towards the implementation of SS in these food manufacturing companies. The external drivers such as Brexit and the potential loss of low-labour cost workforce is driving larger food manufacturing companies towards the implementation of responsive Smart manufacturing technologies. The smaller food producers are focussed on more proactive tools, including how the SS can successfully be used to improve efficiencies on small batch manufacturing, time to market, and promotion of the company on a much wider scale than it currently does. Interestingly, companies see that these external drivers outweigh the internal issues such as training, costs etc and seem willing to overcome these internal barriers as the external drivers seems to be greater than the internal resistance previously seen. Furthermore, simultaneous approach to the issue of implementing Smart technologies in the UK food sector regarding internal and external drivers is another feature of this study because in most previous studies the issue of Smart technology implementation is studied from the internal perspective (training, cost, etc. as being barriers towards implementation). Dividing these drivers into internal and external drivers was the main characteristic of this study that led to different results.

- Although internal drivers such as cost and skills play a role in the decision to implement SS, company directors consider the external drivers outweigh the resistance posed by the internal barriers.
- External drivers for change should be designed in a way that company directors are convinced of the importance and necessity of the need to move towards SS concepts and be convinced that without a move towards SS implementation that economic sustainability of their companies could be compromised
- Studies suggest that the internal barriers around the resistance to change by employees and, the lack of skills and knowledge of the workforce are seen as major inhibitors towards implementing SS, these issues cannot hold back a company's drive towards improving the performance of company operations. Senior managers and leaders of food manufacturing

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companies must provide strong leadership and vision towards implementing SS and to drive up the performance of UK food manufacturing industry.

- Six key enabling features were identified and included: (1) Big data and knowledge based automation; (2) Smart Systems; (3) Advanced Robotics; (4) Cloud based systems; (5) new management paradigms and, (6) new skills and knowledge bases. Their introduction in to this paper is directed towards providing a set of foundation elements for practitioners and managers to focus on when implementing Smart Systems.
- Effective implementation of smart systems requires a business-specific strategy to be defined, to align the business drivers and current capabilities with the desired outcomes. By following this thought process it will be 'standard work' for industrial engineers and academics to successfully intervene in food manufacturing companies and guide them towards a successful smart system implementation, which is directed toward well defined benefits.

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