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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

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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, it is possible to articulate the current challenge within the UK food manufacturing industry in terms of two distinct objectives aimed at overcoming their isolation and, align their businesses towards Smart Systems implementation. These objectives are:

1. Through the development and application of a SS/Sustainability profiling tool in to 32 food manufacturing companies, to understand the current expertise and identify the technological priorities of the UK food manufacturing companies when considering the implementation of Smart Systems
2. To propose a conceptual system architecture for effective SS 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 an implementation framework to be easily leveraged across both the UK and international food sector in order to minimize the learning curve costs and timescales.

2. Literature Review

UK food manufacturers are highly aware of the need to operate within visible supply chains. 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 [8]. 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 [8,14,15]. 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].

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 and in meeting the sustainability agenda such as; improved efficiency, greater customisation, improved quality and reduced waste and enhanced economic sustainability [6]. For instance, Bonilla et al [7] link four different business scenarios (deployment, operation and technologies, integration and compliance) with sustainable development goals. From these scenarios, their analysis resulted in 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). Therefore, further work is required in the form of a more detailed literature analysis of how SS and the issues of how SS can meet the sustainability agenda is required. Section 2.1 develops this work.

2.1 Smart Systems – A Literature Review

Smart Systems (SS) can be defined as the employment of manufacturing and communication 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 that link to the key sustainability dimensions, including the ability to improve food traceability, reduce food waste and increase efficiencies in transport and handling of food products and in turn contributing directly to addressing both economic and environmental sustainability challenges [10,11]. 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]. A further and more detailed literature review of Smart Systems, the technologies and its impact on the sustainability dimensions is shown in Table 1.

Table 1 – Literature Analysis of Smart Systems

Smart Systems Research Clusters	**Smart Technologies and Systems**	**Sustainability Dimensions**
Time compression, time to market.	3D Printing, simulation, VR, customer integration, virtualization [11,14,15]	Reduced development time & tooling cost [16]
Sustainable Product Innovation	Intelligent product design systems [17,18]	Inter-functional collaboration, innovation-oriented learning, R&D investment [17].
Human Factors	Innovation, competency management [19,20]	Work practices, social dimensions, human rights, ergonomics & safety [19].
Knowledge Management	Intelligent Decision Making - predictive scheduling, fuzzy logic systems [21,22]	Organisational and deep learning systems [23]
Energy Systems	Energy neutral technologies through IoT systems [24]	Waste reduction, energy monitoring [25]
Enterprise Reconfiguration	Rapid supply chain reconfiguration through IoT CPS systems, Virtualization [11,26]	Value Mapping & information sharing tools [27]
Collaborative Networks	Customer/supply chain connectivity [26],	Company / Knowledge base collaboration [28], e-WOM, Digital marketing [32-35]
Management Systems	Technology management, control and monitoring [21,22]	
Digital Systems	Digital supply chains, data analytics, cyber physical systems [9,10,29,30]	Big data analytics on environmental impacts [31]

2.2 Smart Systems – Analysis of Literature

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Through undertaking a literature analysis of academic articles that focus on Smart Systems and their connectivity to sustainability, it is possible to identify nine key smart system clusters that have emerged from the work and are shown in Table 1. The analysis has further identified the key SS technologies and systems as well as the connectivity between SS and the sustainability dimensions. This analysis suggests that the development of SS technologies and systems are at an advanced stage of development and, the connection between the sustainability dimensions means that the move towards the employment of SS in industry is likely to impact greatly (and positively) on improving sustainability of companies especially in the economic and environmental sustainability dimensions. Furthermore, this literature analysis as well as supporting evidence such as [8] suggests that the food industry is ideally placed to benefit from adopting SS. 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 [8,36]. Greater flexibility offered by SS 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 [9].

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 research question for this study is therefore: "*what are the current capabilities and priorities of the UK food manufacturing industry to meet the requirements of Smart Systems implementation?*".

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 [37,38]. However, evidence suggests that UK Food companies may not be fully aware of the benefits that SS can bring [18,39]. 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 [41,42].

In summary, the benefits that SS can bring are appreciated by many industrialists and academics alike. Improved product traceability, (including traceability in the food recall system, [43]. Productivity throughput, shorter processing times and improved consistency of product quality are all seen as positive elements of SS implementation. 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.

In order to further understand these issues identified from this literature analysis, 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. Using the SS clusters and technologies and systems identified from this literature analysis as the main guide to the development of the survey tool, the authors undertook the survey to identify some baseline information of how industry leaders are viewing SS adoption in their companies.

3. Research Method and Survey Design

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

1. Analysis of secondary research obtained from academic sources.
2. A small-scale pilot survey of food manufacturing companies (stage 1 research study).

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3. Follow-up interviews with MDs and Managers from the small-scale pilot study (stage 2 research study).

The stage one research process required the development of an appropriate SS profiling 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 primarily based on the work from the literature analysis previously undertaken and. on further literature around manufacturing challenges and SS systems [44-48]. The profiling tool is shown in Table 3. The tool utilises the SS research clusters, SS technologies and sustainability dimensions that were highlighted from the literature review and detailed in Table 1 of this paper to form the main body of the tool.

Companies were selected by the research team based on the definition of a food manufacturing company, 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 configurations*" [40]. 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. Table 2 shows the companies and food sectors who responded to the survey and, the size of each company measured in terms of the number of employees employed. The companies involved in the stage 2 study are marked in square brackets.

Table 2 – Companies and Sectors Responding to Survey – Stage 1 Stage 2 [ ]

Sectors	Companies per sector	Employees 10-50	Employees 50-150	Employees 150-200
Packaging & Logistics	4 [3]	1 [1]		3 [2]
General Drink	2 [1]		2 [1]	
Wines, Beers, Spirits	5 [2]	3 [1]	2 [1]	
Ready meals & processed foods	5 [4]	2 [2]	3 [2]	
Cheese & Dairy	4 [3]	2 [2]	2 [1]	
Bread, Bakery & Snacks	10 [5]	6 [4]	3 [1]	1
Biscuits, cake, chocolate	2 [2]	1 [1]		1 [1]
Totals	*32 [20]*	*18 [11]*	*10 [6]*	*4 [3]*

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. This score was then validated by the researcher undertaking a detailed observational study of the systems and technologies employed within the company. A short moderation session followed the observation and interview with the MD to ensure that consensus was achieved on each driver and dimension that was scored.

Scores were placed against each strategic driver and associated indicative technology and initially focussed upon the current level of expertise the MD believed that their company had against the eighteen technology/systems dimensions highlighted. The second stage of scoring required the MD to prioritise each dimension based on a two-year planning horizon (i.e. where they thought their company needed to be to meet the demands of their industry). This profiling allowed the team to determine the current state of operational excellence and also, the strategic intent of each 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.

Table 3 – Sustainability Profiling Input Sheet.

Smart Systems Sustainability Clusters	Smart Technology Areas	Average Current Level of Expertise	Average 2 Yr Priority Score	Gap	Frequency (Current Expertise)				
					1	**2**	**3**	**4**	**5**
Time Compression, 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
Sustainable 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 Factors (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 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 Systems (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 (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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Following the profiling exercise, the researchers moved to the Stage 2 research 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 from the Stage 1 study and, to understand the complex nature of the priority areas highlighted by the surveyed food manufacturing companies.

4. Results of the Survey and Interviews

A synopsis of the stage 1 sustainability profiling results is shown in this section of work. Table 3 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 technology area. This enabled the researchers to understand the relative level of expertise each company had in relation to the technology areas. Figure 1 focusses specifically upon the sample group's average current expertise profile 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; knowledge base collaboration, organizational learning, digital connectedness and, data analytics. Figure 1 also shows the average two-year priority scores offered by the sample group of companies. The two-year priority profile 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; competency management; digitally connected supply chains and, university/company collaboration. The four criteria of lower concern are; supply chain reconfiguration, customer and supplier collaboration, information sharing and, R+D & Innovation.

4.1. Analysis of Results (stage 1 study)

The findings of the stage 1 survey are shown on Figure 1. The figure represents the current overall scores from all 32 food manufacturers as well as the scores split between the small-SMEs (18 companies) and the Medium SME / Large companies (14 companies). The figure also shows the 2-year priority profile for the 32 companies. The overall findings of the current scores were not particularly surprising. 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.

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 companies felt that their waste reduction strategies were relatively well advanced but, company energy reduction strategies needed further work and development. Of further interest was the identification of the priority to have 'digitally connected supply chains'. Although seen as a strategic priority, the companies did not see themselves having the current expertise (or knew where to access the expertise) in order to move towards this priority area. This issue links strongly with the disparity seen between the current overall lack of development in the areas of competency management, knowledge management and University/company collaboration. However, the companies did see that these areas were critical for meeting their future strategic intent as there was a clear lack of understanding amongst the surveyed companies that in order to move to the adoption of Smart Systems, there needed to be a greater development of staff and, further collaboration with Smart Systems experts that are very likely to exist outside the food industry. The external drivers such as Brexit outweigh the potential barriers and internal issues such as the costs of training and

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equipment etc as they saw the threat of significant external change as being greater than the internal resistance that had been previously seen. Further analysis of the data identified that the small-SME (10-50 employees) performed better on the whole in the deployment and application of internet and smart systems technologies and were better aligned to meeting the social, environmental and economic sustainability dimensions. Although their technologies and systems lacked the sophistication of the larger companies, the application of internet and cyber physical systems pertaining to their own production operations were better developed. This particular issue was further developed in the Stage 2 research study. A particularly well-developed area amongst the small-SME companies is the development of excellent supply chain collaboration practices developed between customer and supplier delivered through internet technologies (internet and social media platforms).

Through the development of closer collaboration within the supply chain, small SMEs benefitted from greater oppprtuniies to develop more customised products and services through co-creativity of new products and innovative solutions to particular production issues thus creating a virtuous circle for these companies. A particular strength of the medium to large companies was their ability to manage their technologies and to operate lean production systems as well as utilizing time compression technologies such as automated production systems, simulation of new production layouts for new product introduction etc. However, whilst these technologies are utilized and well developed, their overall connectivity to Cyber Physical Systems (CPS) which provide the connection to become Smart Systems is missing in all companies surveyed.

Therefore, two distinct patterns emerge from this study that emphasis the difference in attitudes between small SMEs and the medium SMEs and larger companies. Smaller SMEs use less sophisticated technology but utilize their systems to better effect, linking their technologies to both customer and supplier in more of a tradition Smart Systems approach whereas, medium sized SMEs and larger companies employ more sophisticated technologies but, they lack the interconnectivity and CPS technologies to turn their technology in to Smart Systems. The next section of the paper will focus on Stage 2 of the research programme and involves undertaking further and more in-depth interviews with the MDs and senior managers of 20 companies (who participated in the stage 1 research programme). The aim was to attempt to understand further the issues around SS development within their companies and to highlight the drivers and barriers around SS implementation.

4.2 *Analysis of Results (stage 2 study)*

Responses obtained from the companies can be grouped in two strategic themes namely; company strategy and manufacturing strategy.

Company Strategy: The findings of the Stage 1 phase of the study showed that the companies saw the investment in SS technologies and systems were critical to the survival of their respective companies. The driver for implementing such systems over the next two years was however, driven by the concerns over the rise in labour costs that was driven in turn by major political changes around Brexit and the actual and potential loss of highly skilled European workers. Most companies commented on the issue that they had lost on average 30% of their skilled workforce due to the threat of Brexit and, had previously gone through the pain of training and developing local workers but, had largely failed to retain that 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 considering that a significant change in company strategy was needed to respond to the potential political change.

A secondary finding from the interviews highlighted an important issue around future worker recruitment and retention in that companies in general envisaged the adoption of SS would enhance the image of the industry towards being one that was more sophisticated in nature, more environmentally friendly and a more exciting and challenging industry to work in. It was envisaged that the 'knock-on' effect to this image change would be that more talented, technologically focussed

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workers would be drawn to the industry thus reducing the concerns over attracting talent in to the industry.

Manufacturing Strategy: In order to remain competitive and therefore economically sustainable, the primary focus of development within the medium sized SMEs and larger companies was on the continual improvement of manufacturing performance whereas most small SMEs focussed upon innovation and new product development as a means towards maintaining competitive advantage. Therefore, as can be expected, the type SS and associated technologies different considerably (i.e. the need for highly automated and connected SS for larger manufacturing focussed food manufacturers compared to the more internet connected social media oriented smaller SMEs where new products and ideas are identified through closer connectivity with their consumer).

The drive for automated manufacturing SS within the larger companies was driven by 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.

In discussions with the MDs of the smaller SMEs who had a greater focus on smaller production volumes but greater involvement in the design, development and introduction of new food products, it was clear that their respective manufacturing strategies did not involve expanding their businesses to cater for any significant increase in manufacturing demand, preferring to collaborate with larger manufacturers and to outsource responsibility for production if demand dictated. Therefore, smaller SMEs were more likely to seek collaborative solutions with other companies. However, this was not the case with larger food manufacturers who sought to deal with production issues such as new product development etc by themselves rather than de-risk the NPD process through supply chain collaboration with smaller but more expert companies. Therefore, one of the barriers towards larger companies failing to invest in NPD systems and thus to remain and manufacturing only plants was the perceived costs of investment and the risk of failure.

5. Discussion

Company respondents identified the continuing pressure on their companies to continually innovate but also, to reduce production costs and increase production yield in order to remain economically sustainable. As a result of these pressures, most saw the need to acquire a greater level of automation [49]. Most responses from medium to large companies was to move towards 'lights out manufacture' and 24:7 manufacturing and this would rely heavily upon automated systems and technologies. Many large-scale manufacturing facilities already operate partially automated systems. However, the shift towards web based, integrated and automated systems which will ensure productive yield in increased and product quality becomes consistent and repeatable had not yet been made.

The SS technologies and systems that are seen as crucial for implementing in to company facilities are highlighted as: *Big data and knowledge-based automation*: in collecting, analysing and making sense of a wide range of production data and semantic data from multimedia / social media [50] allowing companies to understand customer preferences and personalise products. *Smart Systems:* The immediate application of Smart Technologies and systems to enable businesses to optimize production and also resource management and energy minimization throughout the supply chain [51,10]. *Advanced and autonomous systems:* moving routine food manufacturing operations such as food preparation and cleaning activities in to autonomous and near-autonomous activities through the use of computer vision, sensors including GPS, and remote-control algorithms [52]. *Cloud computing Computerised food manufacturing execution systems*: working in real time to enable the control of multiple elements including enhancing productivity, supply chain management, collaboration, resource and material planning and customer relationship management [49,53,54].

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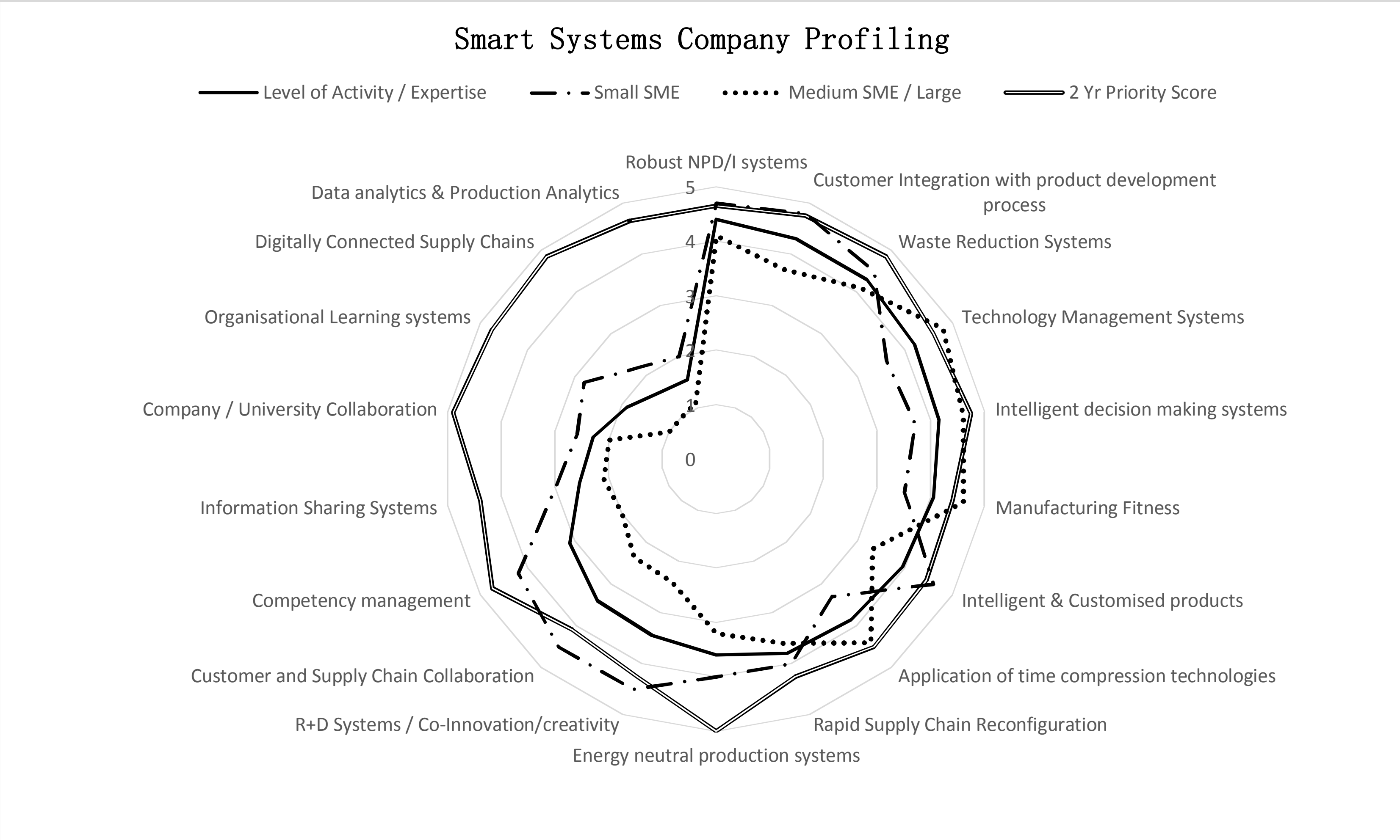

369 **Figure 1** –Analysis of Current and Future Profiles in Ranked Order.

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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, multiple use of crops/waste streams and novel processes to minimise water and energy requirements, are all key issues requiring new management paradigms to effectively manage the complexity of such systems [55]. These issues can be further enhanced through managing Smart Systems through Cloud management, Big Data Analytics and intelligent decision-making systems [56]. Allied to these issues is the need for *New skills and Knowledge Bases:* future knowledge generation and though leadership that will enable the development of "digital thinking" so that companies manage the process in a new way and allow for quicker and more accurate decision making [57,58].

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. The respondents from the small food companies surveyed identified that developing a sound knowledge around digital marketing and e-Word of Mouth (e-WoM) [32-35] [43] is in much demand in order to ensure that smaller companies achieve greater visibility with a wider range of customers and more immediate feedback from clients in order to remain at the forefront of the product development process[59]. Allied to this issue is the enhancement of a company's use of Social Media systems to 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.

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.

6. Future Development of Smart Systems for Food Manufacturing Companies

The features described above have been explored in depth by the authors referenced. However, it is 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 second objective of the research, that of *to propose a conceptual system architecture for effective SS implementation*. One such approach towards identifying the range of SS technologies that can be applied within companies can be through the "digital compass" [43]. The company shown in Figure 2 aligns the eight basic value drivers and 26 practical SS levers. Further analysis of the compass shows that the technologies can be further divided into two sections namely; the '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 align themselves closely with the SS and Sustainability drivers shown in Table 1. 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 vision, companies can select 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 FMCs toward an implementation model that will meet their exact requirements in the shortest

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possible time and smallest implementation cost. 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.

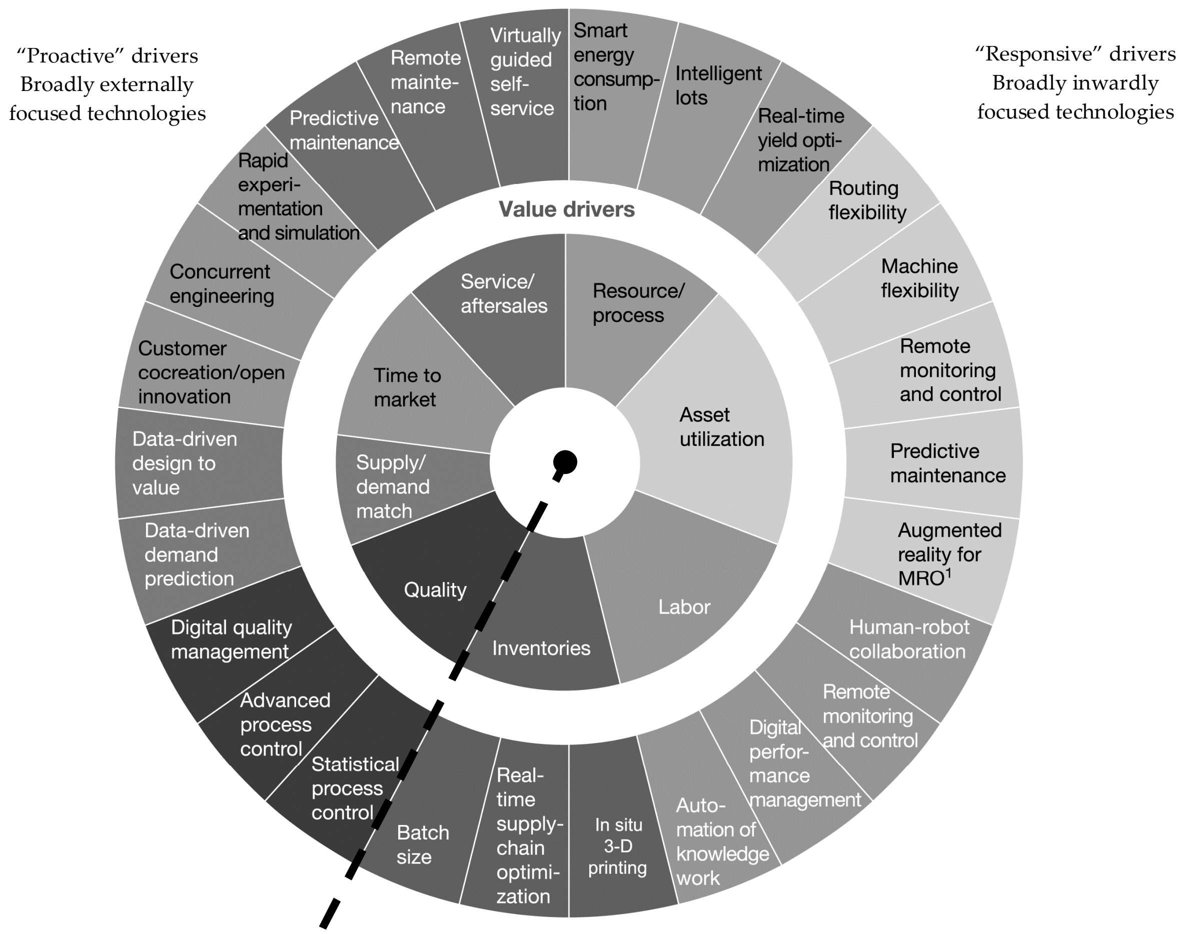

Figure 2 –Digital Compass [43] .

6.1. Towards the Implementation of 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 SS and to link these to their appropriate sustainability dimensions. By engaging with the initial thirty-two companies food manufacturing companies, the 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 3 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.

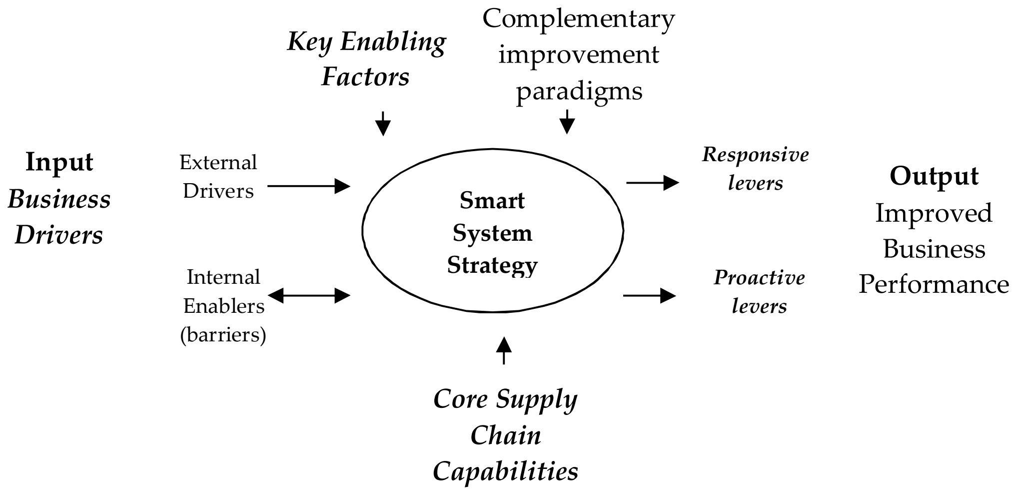

Figure 3 – Schematic of the Smart Systems Implementation Framework.

Business drivers: External drivers including political and environmental factors, changing workforce demographics, and changing customer requirements. Internal dimensions such as attraction and retention of staff, training in requisite skills, and system implementation costs.

Key enabling factors: Including: 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. Lean, Agility and six sigma improvement paradigms drive both the improvement culture and affect the human factors.

Core supply chain capabilities: virtual enterprises, digital marketing and, virtual supply chain environments focusing upon ICT and web technologies by partnering/outsourcing companies [59]. Increase the transparency of operations through to the supply chain in order to achieve greater food security and reliability [60]. Sustainability / resource efficiency: resource and energy efficiency, waste management, recycling [47]. 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 [61].

Proactive / outwardly facing smart system levers : 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 [62]. 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 [61].

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Responsive / inwardly facing smart system levers : 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 [62]. 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 [63].

7. Conclusions

Food Manufacturing Companies in the UK face many challenges and opportunities to achieve economic sustainability. One such opportunity is through the application and implementation of Smart Systems. This study has attempted to develop an understanding of the attitudes and priorities of FMCs to the adoption of SS. Through the application of a new measuring tool developed in this paper, the research team has been able to profile a range of small, medium and large scale food manufacturing companies and to determine the strategic drivers and challenges that these companies have in the implementation of SS. Therefore, the initial contribution of this paper is to propose the development of a unique measuring tool for assessing a company's preparedness and its operational and strategic capabilities towards the adoption of SS technologies and systems. Through the use of this profiling tool and the adoption of the two-stage research approach, the research team has been able to identify a complex range of differing company demand and pressures that means a one size fits all strategy for supporting such companies is going to be largely ineffective and costly [46].

From a theoretical viewpoint, this study contributes to the emerging literature on the relationship between 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 [46]. 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.

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 future political changes and, the associated potential loss of low-labour cost workforce is driving larger food manufacturing companies towards the implementation of responsive Smart Systems. 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.

The major limitation of this study is the limited sample size obtained for the stage 1 survey and stage 2 interviews. Whilst the total response level of 32 companies enabled the research team to identify a number of key themes around Smart Systems within the food manufacturing industry, the work cannot be considered to have any statistical significance and therefore the outputs of the study are to be considered with this limitation in mind. A more comprehensive survey is now underway and the outputs of the study should provide additional contextual information around the findings shown in this paper due to its increases sample size. Furthermore, the limitations found in the outputs

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of this study has initiated a further and more detailed survey questionnaire and a semi-structured interview programme for the next phase of this under-researched area.

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