Creating Resilient Manufacturing Businesses – A Conceptual Fitness Model

ABSTRACT

Over recent years, UK manufacturing industry has experienced turbulence in its business performance. Lower cost products and, responsive and flexible processes are now essential in order for a company to capture new markets and to become economically resilient. Business resiliency is a term used frequently to describe a company's ability to adapt and cope with disturbance. This has led to the generation of many frameworks and models aimed at guiding companies towards improved business performance. However, these frameworks are primarily strategic in nature and do not necessarily focus on creating resilience at an operational level in manufacturing companies.

The authors employ a mixed research approach initially undertaking a literature review and then a screening survey in to twenty-five manufacturing companies in order to identify the key business resiliency techniques employed. Following this, a Focus Group goes on to detail a new manufacturing resiliency model called the Fit Operational Model (FOM). The model's effectiveness is then assessed and adjusted as a result of being implemented in a subject company.

Key Words: Resilience, Fit Manufacture, Operational Model.

Article Type: Case Study

1. Introduction

Manufacturing companies are now operating in less secure and more complex environments. This in turn focuses businesses and manufacturing facilities to cater for a wider range of demands in order to remain competitive (Paiva *et al*, 2012). Lower cost, responsive and flexible products and processes are now essential in order for a company to capture new markets and to become more resilient in nature (Pham *et al*, 2008). Resiliency is a theme frequently used by academics and industrialists to describe the relative robustness of a business.

Fiksel (2006) defines 'enterprise resilience' as the 'capacity for an enterprise to survive, adapt, and grow in the face of turbulent change'. Carvalho *et al*, 2011 describes business resilience as the ability to return to its original state or to a new, more desirable state, after experiencing disturbance, and avoiding the occurrence of failure. The goal of resilience therefore is to prevent the shifting to an undesirable state.

Resilience is often discussed in terms of supply chains and in this case it refers to the ability of the supply chain to cope with unexpected disturbances (Berman, 2009). Ponomarov and Holcomb (2009) provide a definition of supply chain resilience (in the context of manufacturing companies) as "The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function".

In an attempt to achieve improved manufacturing supply chain resilience, academics and industrialists alike have developed a number of frameworks and models aimed at guiding companies towards improved supply chain performance. For instance, Kumar and Antony (2009) identify that organisations are focusing on the ways to establish a resilient business environment by minimising waste from business processes through the application of Six Sigma. Ismail *et al*, 2011 outlines an approach that builds on the premise that manufacturing supply chain resilience occurs as a result of the implementation of both operational and strategic capabilities. The framework they propose is based on their earlier work in the area of manufacturing agility, and involves the integration of agile operations that link in to the overall strategy of the company.

However, it is suggested that the key issue with these frameworks is that they are primarily strategic in nature and have traditionally focussed on the wider aspects of resilience such as, business and/or enterprise resilience and, does not fully focus on creating resilience at an operational level. The main contribution of this paper therefore, is to address the gap in literature created by a predominantly strategic focus on resilience, by providing an empirical study that focuses on the operational mechanisms to achieve manufacturing resilience.

With manufacturing resilience advocating the need for companies to become more impervious to disruptions and also, to quickly return to its previous or improved state after a disturbance has affected performance, manufacturing companies need to become more flexible and innovative in the development of their products and processes (Khan *et al*, 2012). In terms of manufacturing resilience, key literatures suggest the integration of traditional strategic manufacturing paradigms such as Lean and Agility along with business functions such as marketing (Adamides & Voutsina, 2006) ICT, communication and manufacturing technologies and, developing product innovation in order to achieve a more competitive, resilient manufacturing environment (Pham *et al*, 2008).

Christopher and Towill (2000) outline the need to integrate Lean and Agility in order to create a resilient manufacturing improvement strategy and, if implemented correctly, can lead to increased manufacturing capacity, lower unit costs and greater responsiveness. Prabhaker (2001) outlines that in order for this to occur, Lean and Agility needs to be pro-actively aligned to business process elements such as marketing and innovation in order to win new customers. It is possible for a company to be successful in adopting and implementing cost reduction strategies (often mistaken as Lean) and still fail as a business due to the lack of growth opportunities (Ferdows and Thurnheer, 2011, Burnard and Bhamra, 2011). Table 1 summarises the basic precepts of a number of manufacturing and supply chain resiliency frameworks and models proposed by researchers and highlights their limitations. When considering the design and development of an operational resiliency model, Table 2 provides the key features for consideration in the development of such a model. The need to develop an operational resiliency model is driven by the issues surrounding the range and types of model currently developed from within the academic community. The key findings from the review of frameworks/models from Table 1 show the following limitations:

- Few frameworks were developed as a result of industry collaboration. Most were developed from an analysis secondary academic literature.
- The frameworks and models are focused upon the application of a single paradigm approach towards achieving supply chain resiliency rather than the creation of single unified model that effectively connects the key elements of a number of key strategies in to one framework/model.

- The frameworks proposed lacked an operational perspective towards implementing a dual strategic/operational level approach towards resiliency.
- Few models focused on the application of tools and techniques of resilience at an operational level with little focus on integration with the strategic objectives of the business.
- Whilst the frameworks developed were novel, they did not fully consider the integration of a number of key Business Improvement Methods to create a unified manufacturing operations improvement strategy.

In order to plug the methodological weaknesses found in some of the previous frameworks/models e.g. the lack of integration of business improvement methods resulting in an incomplete strategic view, single paradigm implementation etc, this paper proposes a Fit Operational Model (FOM) and shows its design, development and implementation in a subject company. Certainly, when analysing the wider body of knowledge pertaining to resiliency, little information exists around the development of manufacturing resiliency. Whilst much of the work concentrates upon developing the theoretical base for resiliency and, some work exists on observing resiliency from various perspectives (ecological, disaster management etc, Bhamra *et al,* 2011), information pertaining to the implementation of a resiliency framework and, the subsequently measuring its effectiveness is rare.

Therefore, in order to develop and implement the FOM, a case study approach is adopted followed by the application of the FOM in a single subject company. The reason for adopting such an approach is that it has allowed for a closer and more detailed observation of the developmental life cycle of the company. Such case study observations are well suited to relatively new research topics, especially where the phenomena are poorly understood and characterised (McCarthy, *et al* 2006).

2. Research Approach

The Fit Operational Model (FOM) is developed based on a combination of existing academic literature and primary data collected initially from a twenty-five company survey. This survey acted as a screening survey aimed at identifying the key business process improvement techniques being employed by companies. Following the screening survey, a Focus Group (FG) was developed and, through using the consensus theory approach, accurate feedback and consensus amongst the group members towards FOM development was obtained. The work was supported further by a case study in to the implementation of the conceptual FOM and through mapping of the findings against secondary data collected by critically analysing models/frameworks proposed in the literature on BPI initiatives in companies. The authors adopted the research methodology outlined by Kumar *et al*, (2012) in their study of Six Sigma adoption in SMEs as this was seen as being particularly robust and useful to the type of study undertaken by the authors.

The FG consisting of engineers/managers from eight high performing manufacturing companies (each company showing a turnover in excess of £20Million, employing more than 35 staff each and operating as Tier 1 suppliers to industry) was used identify the key issues in the implementation of formalised business improvement frameworks. All managers/associates had substantial industrial experience and knowledge in the implementation of Business Improvement Programmes (BPI) such as Lean, Six Sigma, TPM etc. An academic team made up of the authors of this paper who were all doctoral level qualified and established research experts in their field formed part of the FG in order to provide wider academic input and to generate discussion around the use and development of a more comprehensive range of BPI projects.

The FG also enabled the researchers to investigate the barriers and impediments that these companies overcame in order to achieve successful implementation. The FG also investigated the implementation frameworks and maps used by companies to deploy business improvement projects across their organisations. The viewpoints of the FG members was very useful in understanding the true picture of companies on their continuous improvement journey and, for the empirical development of the FOM. For more information on the earlier stage developments of the FOM, the reader is referred to the work of Pham & Thomas (2012) and Pham *et al* (2011).

2.1 Towards a Model for Change

A conceptual FOM was developed from the academic literature obtained from the analysis of the work developed in Tables 1 and 2 and is shown in Figure 1. The development of the conceptual FOM provided for a starting point in the design stage of the programme.

Five FG sessions were held, with two being held to design the conceptual model (the other three focus groups being; two manufacturing/detailed design focus groups and an implementation focus group). The focus groups worked on the development of the model with the industry members providing the broader manufacturing 'sense checking' required to ensure the academic information could be contextualised and implemented. The industrial partners also acted as gate leaders for driving the model implementation at later stages of model testing. Details of the outcomes of each focus group meeting are now outlined in order to identify how the FOM was established.

The purpose of Focus Group 1 (FG1) was to understand the business improvement projects being undertaken in each FG member company and to establish best practice. What was clear from this FG was that each company had established a clear approach to business improvement and had 'bought in' to the defined BPI paradigm selected by their companies. The aim of the FG was not to substantially change mindsets with regards to changing the way in which the companies worked rather, the focus was on identifying the weaknesses that the managers/associates felt existed in their BPI programmes and, in relation to the complexity of their production systems. This then enabled the academic team to work on establishing the gaps that existed with each BPI programme. Clearly, the single paradigm approach worked well for the companies but they all recognised that their respective programmes did not fully deliver against the many competing demands faced by their companies.

FG2 focussed the group around developing a 'future state' and towards developing an idealised business improvement model. Through systematically identifying the key elements of each of the respective BPI programmes, it was then possible to establish their limitations and then the need for ensuring the weaknesses of one approach is covered by the strengths of another BPI approach. What emerged here was the need not to fully embed the complete BPI methodology of one over another but to usefully adopt the most appropriate part of one BPI methodology in to another so that the resulting model becomes more robust and manages to move towards an optimal solution.

The FG members highlighted the issue that although single paradigm approaches were effective, they tended to be implemented towards achieving ‘cost down’ and to drive greater efficiency and operational improvement. Where it was felt that BPI initiatives failed was in the product development process. Traditional BPI approaches were seen to reduce a company’s ability to innovate and to provide effective product development solutions and/or improvements to existing product services. It was felt that in most cases, the companies could only effectively lower product costs as their only competitive advantage over their competitors. Therefore, the need to establish a multi-channelled BPI approach was identified.

The development of a multi-channelled approach towards achieving both manufacturing/operational efficiency whilst also ensuring that New Product Development and Introduction is simultaneously developed is central to the FOM. Figure 1 shows the conceptual development of the multi-channel system. Consider Product A is a long established product whose manufacturing output is relatively static. In this instance, it can be assumed that the product has reached the ‘maturity’ stage on its Product life Cycle and so volume requirements are consistent. Therefore, its production system is attuned to meet product volume requirements and its supply chain and business systems are synchronised to meet demand. In this instance the FOM will measure the sales output at the end of the system and will feed this information to the start of the model. From here, the information is fed to the controller and will focus operations on to the manufacturing improvement loop. The aim of the FOM in this instance will be to systematically reduce production costs and become leaner and more agile/responsive to market demands. The application of Six Sigma enables production problems to be targeted and systematically resolved whilst the application of Total Productive

Maintenance (TPM) will enable increases in machine uptime and improvements in product quality to be achieved thus creating a resilient and robust production environment.

Alternatively, Product B is a well established product. However, production volumes are being adversely affected and that a clear downturn in customer demand has been identified. In this instance, the product is seen to lie on the ‘decline’ stage of the Product Life Cycle (PLC). A company will therefore need to take action either in the form of updating its product or, introducing new products in to its portfolio in order to offset the drop in sales volumes. Therefore, the FOM will measure a continuous product volume drop at the sales monitor and will feedback the information to the start of the FOM. Here, an analysis will be undertaken as to the root cause of the problem and, if deemed necessary, the FOM will refocus operations by moving towards the upper loop (product improvement loop) to concentrate upon new product development and improvement. On this loop the company will need to validate its core competencies and match them against the new opportunities and markets. This will be done in relation to the current knowledge, skills and technologies in the company and will identify what these will need to be for the future in order to secure future growth. The knowledge management and innovation stage of the model identifies and resolves the knowledge and technological gaps that exist in the company which prevents new products and markets from being exploited.

The FOM identifies the need for the company to operate both loops simultaneously but will apply greater focus on the specific loops at certain times depending upon where their respective products are on their PLC. The performance of each loop is monitored by continuous analysis of sales volumes and by measuring and analysing the operational measures of Quality, Cost

Delivery and Flexibility (QCD, 2004). Common to both loops is the need to reengineer its supply chain to ensure that the supply chain and value adding processes are correctly synchronised to the demand chain requirements.

FG 3 and 4 focussed upon the development of the FOM and to take it towards implementation. The conceptual FOM shown in Figure 1 is a development of the current Fit thinking paradigm (Pham *et al*, 2008) and (Ferdows and Thurnheer 2011) and on the systems base methodology advocated by Parnaby and Towill, (2009) and Fiksel, (2003). Although these approaches to Manufacturing Fitness offer a strategic overview of the resilience paradigm, the FOM proposed in this paper employs a number of key manufacturing management and business improvement methodologies from these initial models. Each of the elements of the FOM is now described in more detail.

2.1.1 Core Competency Development (CCD)

The FG members highlighted the need to develop and extend an organisation's core competency so as to enable the company to extend its design and manufacturing capabilities which in turn leads to the development of clear competitive advantage and hence a resilient manufacturing capability. The issue of developing a company's core competency in order to achieve improved competitive advantage formed the basis of the initial work of Barney (1986). This work was extended by, Prahalad & Hamel (1990) where they identify 'core competency' as a specific set of skills and/or production techniques that deliver additional value to the customer, thus enabling an organization to access a wider variety of markets. Gilgeous & Parveen (2001), identify eight core competencies. These are: strategic competence; functional competence; individual competence; competitive competence; capability competence;

congruency competence; insight/foresight competencies; frontline execution competencies. The 'core competencies' seen by the FG members as being key to the development of their manufacturing organisations and hence important for the inclusion in the FOM are: *strategic competence; distinctive competence; individual competence; competitive competence*. It is suggested therefore that the initial stage of the Product Improvement Loop, that a company considers and develops the key core competence themes on a continual basis in order to remain fully competitive.

2.1.2 Lean and Agility

The focus group members highlighted the need to concentrate on the removal of waste from the production process alongside the need to make a company more responsive and agile to customer needs is key to its continued resiliency (Ismail *et al*, 2011). This is also supported by the work of Christopher and Towill, (2012). Christopher (2000) outlines Agility is a business-wide capability that embraces organisational structures, information systems, logistics processes and, in particular, mindsets and identifies the key characteristic of an agile organisation as flexibility. Christopher goes on to highlight that, whilst leanness maybe an element of agility in certain circumstances, by itself it will not enable the organisation to meet the precise needs of the customer more rapidly.

Meredith and Francis (2000) focus on the development of the 'agility wheel' and identify sixteen features of agility that are categorised under four key headings namely; agile processes, agile linkages, agile people and agile strategy. The key features that the FG identified as being the key drivers for creating a fit company were; flexible assets and systems, fast new product acquisition, deep customer insight, rapid problem solving and aligned suppliers.

Therefore, within a company that serves many customers each having different and competing demands by way of product mix and volume requirements, the FOM advocates the need to develop a company's capabilities to be both agile and lean but having the capability also to switch effectively between the two approaches as and when demands necessitate.

2.1.3 Six Sigma (SS)

Kumar *et al*, (2011) within their work establish a strong basis for employing Six Sigma as a business improvement methodology capable of leading a company to becoming resilient. Drohomeretski, *et al*, 2014 highlight the interconnections and competing feature of Lean, Six Sigma and Lean Six Sigma and highlight the need to consider the careful application of these Business Process Improvement methodologies for different manufacturing scenarios. The focus group highlighted the benefits of integrating Six Sigma in to the Lean methodology in that Six Sigma provided a mechanism in which to systematically (through the DMAIC cycle) resolve problems and remove production based barriers towards the implementation of the overall FOM.

2.1.4 Total Productive Maintenance (TPM)

TPM has long been an integral part of the Lean manufacturing philosophy. For instance, the FG members all deployed TPM methods and practices to some extent within their manufacturing organisations with the complexity and depth of maintenance activities varying by company and type of operational system employed. Brah and Chong (2004) and Bartz *et al*, (2014) outline that increased global competition has augmented the importance of TPM in obtaining and maintaining a competitive advantage and suggests that many organizations are employing TPM to enhance their competitive position. Their work goes on to highlight the positive impact that TPM has had on the performance of organisations and suggest that maximum effect is seen when TPM is an integrated in to all the business functions within a company.

FG 4 primarily focussed upon the NPD/I loop and identified the key elements of the system. A number of key questions were asked of the FG regarding NPD/I. These included, the identification of the barriers and inhibitors towards developing and new and innovative products and taking them to market successfully. The FG members highlighted three key elements within the Product Improvement Loop. The elements of the Product Improvement Loop are now discussed in further detail.

2.1.5 Knowledge and Innovation Management (KIM)

The focus group members outlined the absolute necessity to ensure that knowledge generated is correctly protected and managed effectively to the benefit of the organisation concerned. Therefore, once the core competencies are developed and strategic competitive advantage is achieved, then protecting and capitalising on the knowledge generated is then key to achieving resiliency. Knowledge sharing and management has been widely considered to be a key issue in enhancing the innovation capability of companies (Sáenz *et al*, 2009). Umoh and Amah (2013) outline in their study of thirty-four manufacturing companies that knowledge management enhances organizational resilience. More specifically, it was concluded that knowledge acquisition, knowledge storage, knowledge sharing and knowledge utilization enhances organizational adaptation, organizational resourcefulness, and organizational learning

2.1.6 Technology Integration (TI)

The FG members identified the importance of integrating Advanced Manufacturing Technologies in to the New Product Development stage of the model. The use of 3D printing and Computer Aided Engineering technologies are able to develop concurrent engineering capabilities and move towards right first time manufacture and robust design approaches. The use of such technologies enabling design departments to estimate product costs within a virtual manufacturing environment (Lin *et al*, 2011)

2.1.7 New Product Development and Introduction (NPD/I)

The need to continually develop new products and bring them to market quickly and effectively has long been a driver towards achieving resiliency in companies and supply chains (Khan *et al*, 2012). The FG identifies the need to effectively integrate a company's design and manufacturing technologies with the development of new and innovative products (van Hoek and Chapman, 2006) ensuring a continual stream of new and innovate products are brought to market in ever decreasing lead times.

2.1.8 Supply Chain Reengineering & Resilience (SCR)

Building supply chain resilience can help to reduce and overcome exposure (vulnerability) to risks (Scholten, *et al* 2014) through developing strategies that enable the supply chain to recover to its original (or an improved) functional state following a disruption (Jüttner and Maklan, 2011). Christopher and Peck (2004) develop a conceptual model of a resilient supply chain from a system-level perspective. Their research identifies four primary capabilities for developing resilience namely: supply chain re-engineering; collaboration; agility; and risk awareness. The FG members considered the above primary capabilities in the development of this stage of the model with particular emphasis on the supply chain re-engineering aspects of the model.

2.2 FG 5 Model Implementation – Case Study Implementation

The case study in to a company called THM involved a detailed business review and the application of the FOM over a three year period (2010-2013) via two KTP programmes that ran concurrently. The aim of the study in to THM was to:

1. To implement a Fit Operational Model (FOM) that is validated through rigorous in company testing.
2. Identify the sequence in which the elements of the FOM are best employed in order to achieve increased resiliency in the company (with a view to adjusting the FOM as a result).

THM is a specialist precision engineering manufacturer and is categorized as a profile 2[1] company as outlined in the categorization work undertaken by Thomas *et al* (2008). It currently employs 14 staff of which 10 are direct production staff. The company has invested in 'state of the art advanced manufacturing and design technology' which has given them an opportunity to develop and enhance their product range as well as being able to reduce design and manufacturing lead times.

However, by 2010 THM Ltd were in financial trouble. The market share they expected to capture had not materialised and there were significant problems with introducing new

[1] Profile 2 companies are identified as companies who operate within highly competitive markets but who have significant growth aspirations. However, profile 2 companies generally lack the knowledge, capability and capacity to grow significantly by themselves. Their technological capacity is high but often they lack the ability to fully utilise the technology or enhance or improve the technology once in service

products into the market. Product quality was poor and production output was erratic and low. Of immediate concern was the need to address the operational losses emanating from the manufacturing process. With 23% of product cost attributed to material and a further 62% being attributable to labour, manufacturing and conformance costs, it was clear there was an immediate need to stabilise the production system and systematically reduce the cost of production thereby returning greater profit margins.

A manufacturing team was set up in the company which consisted of the authors of this paper and, a team of five company associates and two KTP associates who were given the responsibility to implement the FOM. The FG members agreed to act as monitors and advisers to the programme. This case study outlines a three year Fit implementation project in which the application and validation of the FOM is detailed.

2.3 Model Implementation

In order to implement such a large-scale multi-paradigm project, the team believed it essential to ensure that the company and all of its staff were fully prepared for the changes the company were going to encounter. The work of Kumar *et al*, (2011) and that of Kumar and Antony (2010) and Spina *et al*, (1996), stress the issue of ensuring company 'preparedness' before venturing in to the full implementation programme.

Therefore, the team spent the first six months of the programme raising awareness of the implementation process amongst the staff as well as undertaking extensive Work Based Learning training sessions with staff in order to develop expertise in paradigm implementation. Also, the team delivered practitioner level training to production staff who would need to carry out much of the practical tasks (autonomous maintenance, problem resolution through Six Sigma teams etc). Most importantly, the senior management and board members of the company were given awareness sessions and were asked to sign up to the programme delivery. With an investment made in the employment of two KTP Associates it was not difficult to obtain senior management buy in to the project.

The initial stage of FOM implementation was in undertaking a detailed analysis of the core competencies that the company believed it had as well as the competencies it needed over the next three years. This work was undertaken with the senior management, board members and all company staff. It was critical here to ensure that current and future values were agreed upon jointly and that the company were fully aware of the investments required in moving towards a new order.

Following on from the core competency development stage, the company set about the development of a knowledge management system. This system was seen as critical to company success since it was required to not only track and monitor the skills and knowledge developed by staff through the project but also enabled the company to identify future skills and knowledge gaps that would assist in defining the knowledge requirements for future employment. The KM system also tracked training and knowledge acquisition and measured the effectiveness of such knowledge on whether the capabilities of the company enhanced as a result.

The company then moved on to the key stages of the FOM. Here, detailed discussions with staff at THM was undertaken in order to outline the key product lines and their respective position on their product life cycles. His was done in order to identify an appropriate operational improvement approach for each individual product line. A detailed costing exercise was then undertaken in order to understand the profitability of each product line and this data was then fed in to the FOM team. As a starting point, it became clear that there was an immediate need to reduce the costs of production on all of the company's products as a matter of urgency, the starting point for the model development was therefore to tackle the 'manufacturing improvement' loop of the model. A pilot product line was chosen to apply the FOM with the intention that further product lines would be tackled after success was seen on the pilot programme. In this way, the team could also update and modify the FOM after each product line improvement project in order to systematically and incrementally improve the FOMs effectiveness. With the pilot product line showing the classical issues of low profitability and continual quality problems, the focus of the team was on the manufacturing improvement loop in the first instance. Figure 2 shows the FOM with its interconnected elements.

The initial stage on the manufacturing improvement loop was to implement the Lean paradigm. During the core competency stage the team focussed on identifying the value chains of the company. The FOM team then identified a value chain that they agreed would be of particular interest to develop through applying the FOM. In the lean implementation stage the team then focussed on a value stream within that chain and then systematically progressed through the five key Lean stages. In order to facilitate this, the team employed the Six Sigma DMAIC cycle since it was felt it provided a simple yet effective approach to progressing the Lean cycle. Therefore, at stage one of the Lean Cycle – Specifying value from the customer's perspective, the DMAIC cycle was applied in the following way. *Define* – identify and define clearly the voice of the customer. *Measure* – measure accurately the key features of the product or service that the customer values. *Analyse* – analyse whether the company meets the customer's idea of value, identify the gap between the customer and company and identify ideas of closing the gaps. *Improve* – identify the future product offering so that the customer requirements are fully met on time and, in full (this will be used in the future value mapping exercise later). *Control* – Freeze the new order.

Once this stage was complete, the team moved on to applying the DMAIC cycle to the second stage of Lean, that of Align the Value Stream. Here the work undertaken was: *Define* – Map the current value stream, *Measure* – measure the value and non-value added activities, throughput times etc. *Analyse* – create a future state map outlining clearly the idealised state. From here, analyse the gaps present and formulate improvement strategy. *Improve* – enact improvement methodologies to move towards future state. *Control* – freeze new order. It is important to note that at this stage the company had identified the need for a quick and rapid response to this product since the customer had identified that the company was not competing effectively against its competitors. This therefore triggered the Agility cycle of the FOM.

The DMAIC cycle was integrated in to the Lean cycle before returning to the core competence stage of the FOM. When the team had reached stage three of the Lean cycle (create flow), the need to ensure that the company's machinery and equipment was able to respond reliably to the demand placed upon it. At this stage, the company started to employ the TPM cycle with particular focus on initially developing a company-wide maintenance plan and then, deploying an autonomous maintenance programme. The TPM system connected neatly to the Agility cycle where the need to ensure the company had flexible assets and systems.

The agility cycle is central to connecting the manufacturing loop to the product improvement loop. Figure 2 shows its importance to connecting the various cycles together. The key features of agility, those of rapid new product development and flexible assets and systems connect directly in to the product improvement loop and the NPD/I cycle. The end stage of the agility cycle connects the supplier alignment stage to the supply chain re-engineering element of the FOM.

When moving to the NPD/I cycle (the product development loop) the cycle starts at the core competency stage and then follows the route through to Technology Integration (TI) and then on to the NPD cycle. Following the core competency analysis, the company identified a possible opportunity to work within the oil and petroleum industry. The company contacted a petroleum maintenance company with a view to offering a design and manufacturing service.

As part of a tendering process for new work, the company developed its TI and NPD stages of the loop and utilised their advanced computer aided engineering capabilities to develop virtual prototypes before engaging with a University department to develop 3D printed models of a product. THM were successful in obtaining this order and was required to take the product to finished product stage. Here the company engaged the manufacturing facility to manufacture the product and identified and aligned its new supply chain accordingly.

During the FOM implementation cycle, the model undertook a number of iterations before the team settled on its correct construction. The team repositioned the Core Competence Development (CCD) cycle to be central to both the manufacturing and product development loop. Initially the CCD lay on the product development loop only. Secondly, the repositioning of the Agility cycle to become much more of a central driver and connecting stage between the two loops was critical to the success of the FOM implementation.

3.0. Results and Observations of Case Study

Since 2013 the company has made slow yet steady progress towards achieving resiliency and is now in a better financial position by fending off imminent insolvency. However, whilst the company is in an improved financial position, it will always face the challenges of remaining resilient, but now it will be able to do so by controlling two distinct value generating streams thus mitigating risk and improving company resilience.

The issue of measuring the resiliency of the company now became a key issue. In order to ensure a full an accurate analysis of the effectiveness of the FOM, there is a need to objectively measure the success of the FOM. However, a single and coherent system for measuring business resiliency were not found. Although, instruments for measuring resiliency were seen to exist in healthcare, disaster management and ecological systems, they were not suitable for use (or be able to be adapted for use) in measuring business resilience. Therefore, with the lack of a clear resiliency measure available, the authors used the seven QCD measures framework (QCD, 2004) to measure the growth and increase in manufacturing performance of the company as this could provide a distinct measure of the ability of a company to ‘bounce back’ from significant disruption. The success of the programme has been measured against eight key QCD measures (seven measures as defined by the DTi and a further eighth measure was included which identified the number of new products developed and brought to market).

Figure 3 shows a radar plot of the key QCD measures (scaled to ensure all measures fit on plot).

The figure shows the results for the three-year period during which the FOM was implemented and subsequently developed. An initial benchmarking study was undertaken in which the company was measured against the eight key criteria using the QCD calculations (QCD, 2004). It was decided to use this objective marker of analysis to support the qualitative analysis made by the authors and to assist in triangulating the outputs (the others being observation, and focus group feedback).

The authors measured the company prior to the start of the FOM implementation programme and then took an official end of year audit at end of each of the three years. In each successive year, it is possible to see steady improvement in each of the QCD measures. However, whilst improvements in OEE values was relatively modest, the measures with the greatest impact were seen as; yield per unit area and, value add per person as well as people productivity. This indicates that the FOM was particularly effective in developing the effectiveness of the workforce towards achieving world-class performance. Product quality consistently improved from 12ppm to 6 ppm in the three years.

4.0 Conclusions

This paper proposes a resilience model called the Fit Operational Model (FOM) as one approach within a more complex multi-channelled support system for UK manufacturers to drive their businesses forward and to make the journey towards increased competitiveness and resilience.

The key contribution of this article was the development (and application) of a resilience model known at the FOM that integrates the key antecedents of manufacturing supply chain resilience into a single operational model. The proposed model aims to provide a structured approach to simultaneously integrating the key business improvement paradigms into a single thread approach to achieving manufacturing resilience. Whilst the key elements of the model was derived from the secondary literature and review of existing academic models, the industry case study provided the operational context in which to develop the model structure and identify the order and nature of the FOM. Therefore, the integrated nature of the secondary and primary phases of the project worked effectively to provide a robust and validated model.

It is not only imperative to drive improvement from implementation of the FOM but also to sustain the gains over the long-term. The Knowledge and Innovation Management stage of the FOM and the iteration loops within the model offers a mechanism to sustain the benefits from its implementation by focusing on intrinsic motivation of employees and sharing the learning across the firm. The product improvement loop of the model enables companies to absorb the external disruptions generated from new market penetration and new product development.

The FOM is equally applicable to all sizes and types of industry. The application of the FOM in this paper was with a struggling SME where it was possible to see that it was possible to apply the model effectively with minimal financial outlay.

The FOM is still in its early stages of development and thus the research area and the FOM requires further work and enhancement in order to develop its wider applicability to manufacturing companies. Whilst the model has been tested on a subject company, further testing and improvement of the model is required by conducting case studies into a wider cross section of companies and also, seeking suggestions for improvement from world-class organisations, academics and practitioners. The authors are currently working on establishing the timeframe for the implementation of the FOM in selected companies from both the aerospace and automotive industries with wider ranging plans to roll out implementation to the manufacturing industry as a whole. From this wider implementation it will be possible to ascertain the relative importance of each element within the FOM and how these elements interact depending upon the size of company (large, SME) and industrial type (aero, auto, electronics etc).

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Table 1 Review of Manufacturing Resiliency Frameworks and Models

Author	Methodology Applied	Key Themes Highlighted	Focus of model/framework
Kumar *et al*, 2011	Six Sigma framework for SMEs developed through a triangulated Research Methodology	Development of Six Sigma Model and Framework for manufacturing SMEs aimed at improving company resilience.	Limited in scope. Focus on Six Sigma implementation to achieve resiliency.
Burnard and Bhamra, 2011	Analysis of Resiliency models built upon analysis of existing secondary literature in to resiliency.	Resilience enables companies to become sustainable through being able to respond rapidly and effectively to threats and to mitigate them effectively. Paper proposes a number of resiliency models which include detection and activation model, resilient response framework etc	Focus is on organizational resilience and focuses upon resiliency from a strategic perspective. Frameworks and models are conceptual in nature
Demmer *et al*, 2011	Through a case study approach the authors identify the key antecedents of resilience in large companies and defines metrics for SMEs.	Defines 7 key antecedents of resilience in large companies and defines metrics for SMEs towards developing a resilience model for SMEs.	Focused primarily on strategic business issues. SME metrics based around development of networks, scanning landscapes etc
Gunasekaran *et al*, 2011	Comprehensive literature review that defines the features of resilient SMEs. Framework is tested using	An SME framework is developed that focuses upon resilience and competitiveness	Framework identifies key issues such as technology, supply chain integration, organizational behavior, quality and marketing as being key

	primary research findings.		issues in developing resilient SMEs.
Ismail *et al*, 2011	Uses a mixture of primary data (KTPs etc) alongside secondary information on resilience to define new model.	Framework identifies the need to align strategic agility issues such as Quality, Cost, Flexibility, Service (QCDFS) etc to correct business improvement tools to ensure a robust and responsive organization.	Describes a practical 'top-down' strategic framework to assist manufacturing SMEs to develop a degree of resilience when operating in turbulent business environments.
Khan *et al*, 2012	An in-depth case study methodology was developed to uncover the strategies undertaken by a fashion retailing company to create a competitive advantage through its management of the product design/supply chain alignment and the creation of resilient supply chains.	The study develops a framework that looks in particular at integrating product design and the supply chain to enable the company to develop resilient and responsive supply chains.	Supply chain oriented work that outlines a strategic rather than an operational framework that focuses upon resilience only.
Ates & Bititci, 2011	A study based on a multiple case study methodology through semi-structured, face-to-face interviews with 232 senior managers in 37 manufacturing SMEs across Europe focusing upon the connection between core	The work outlines that resilience in SMEs will be enhanced by the ability to embrace organisational and people dimensions as well as operational aspects of change management, and paying attention to long-term planning and external communication to drive	A strategic resiliency framework is developed from primary data analysis. No operational model developed from study.

	capabilities and manufacturing resilience	change proactively.	
Pham & Thomas, 2012	Review of secondary data and the development of three SME case studies to test proposed framework	Fit Manufacturing Framework is proposed that interlinks the concepts Lean, Agility and Sustainability to achieve manufacturing resiliency	A strategic resiliency framework is proposed but no operational model is developed.
Ferdows & Thurnheer, 2011	The paper examines the process of design, launch, and management of a fitness program in 42 factories of the Hydro Aluminum Extrusion Group on five continents between 1986 and 2001. The design was based on the "sandcone model" proposed by Ferdows and DeMeyer but the sequence of capabilities was modified to improve safety, reduce process variability, codify and share tacit production know-how, improve responsiveness, and improve labour and machine	A fitness regimen provides a roadmap for improving core capabilities in a factory. It is different from building leanness. Fitness helps the factory become leaner, but the opposite is not always true. A factory can become too lean but never too fit.	A strategic model is proposed that outlines four key measures namely: improve safety; reduce process variability; codify and share tacit production know-how; Improve responsiveness; improve labour and machine efficiency. .

	efficiency		
Fiksel J, 2003	This work provides a systems based resiliency protocol based on the extension of secondary data analysis. A conceptual model is developed that investigates initially the issue of sustainability from which the issue of systems resiliency emerges.	The Author develops a systems based approach and provides the connection between resiliency and sustainability. Proposes the concept of resilience enabling organisational survival and that resilience is to be viewed as an inherent system property rather than an abstract goal.	Author develops through a theoretical development a systems design protocol that involves; identifying system function and boundaries, establishing requirements, selecting appropriate technologies, developing a system design, evaluating anticipated performance, and devising a practical means for system deployment.

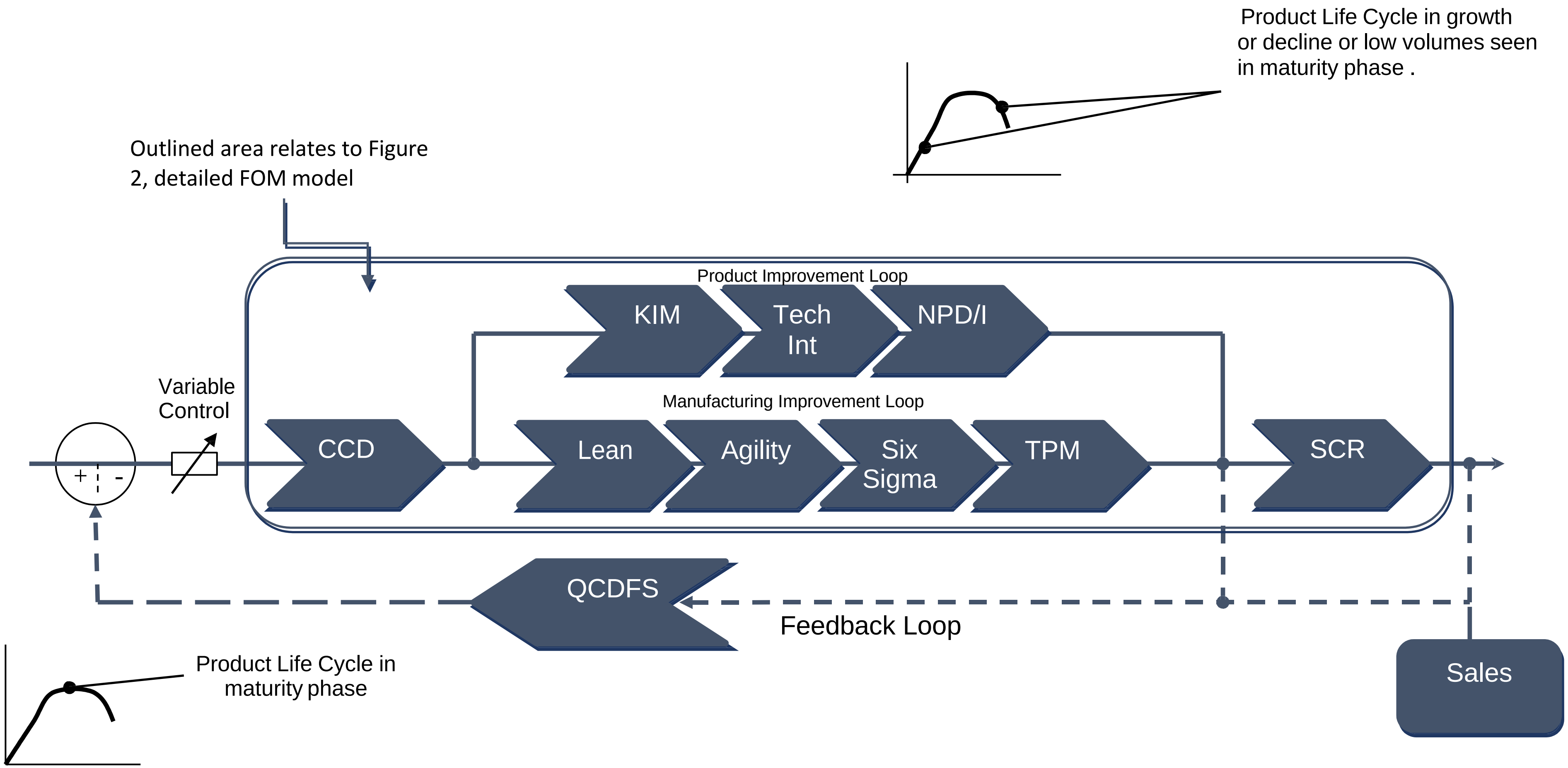

Figure 1 The Conceptual Fit Model (CFM)

Feature of Resilience	Source
Six Sigma as a key resilience driver	Kumar *et al* 2011
Technology and Supply Chain Integration, Quality, Marketing and organisational development	Gunasekaran *et al*, 2011 Adamides &Voutsina, 2006
Using key measures of performance to measure resiliency– QCDFS	Ismail *et al*, 2011
The need for operational models aimed at achieving manufacturing supply chain resiliency. Models need to contain both strategic and operational elements	
New Product Development and reduced time to market of new product introduction	Khan *et al* 2012
Systems reconfigurability, supply chain reengineering. Systems based view of resiliency.	Rodríguez-Díaz & Espino-Rodríguez, 2006 Fiksel, 2003
Agility, business flexibility, manufacturing strategy and New Product Development	Christopher, 2000
Improved safety; reduce process variability; codify and share tacit production know-how; improve responsiveness; improve labour and machine efficiency	Ferdows and Thurnheer, 2011
Leanness	Achanga *et al*, 2006
Integration of Lean, Agility and Sustainability to achieve manufacturing resiliency	Pham *et al*, 2011
Knowledge Management and core company competencies and the change process in companies	Paiva *et al*, 2012, Ates & Bititci, 2011
Knowledge Based View	Ambrosini & Bowman, 2001

Table 2 Key Manufacturing Resilience Themes

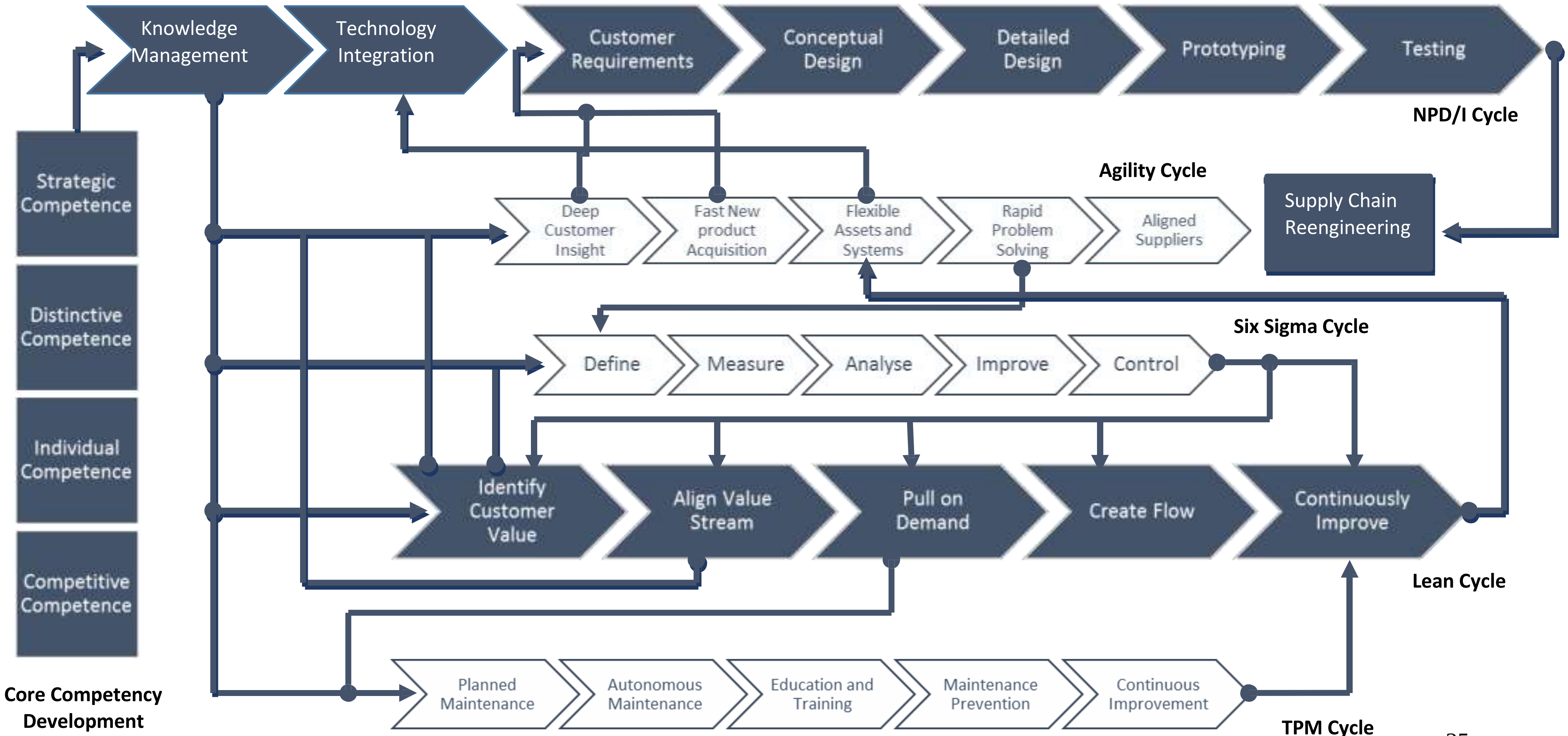

Figure 2 Detailed Development of the FOM

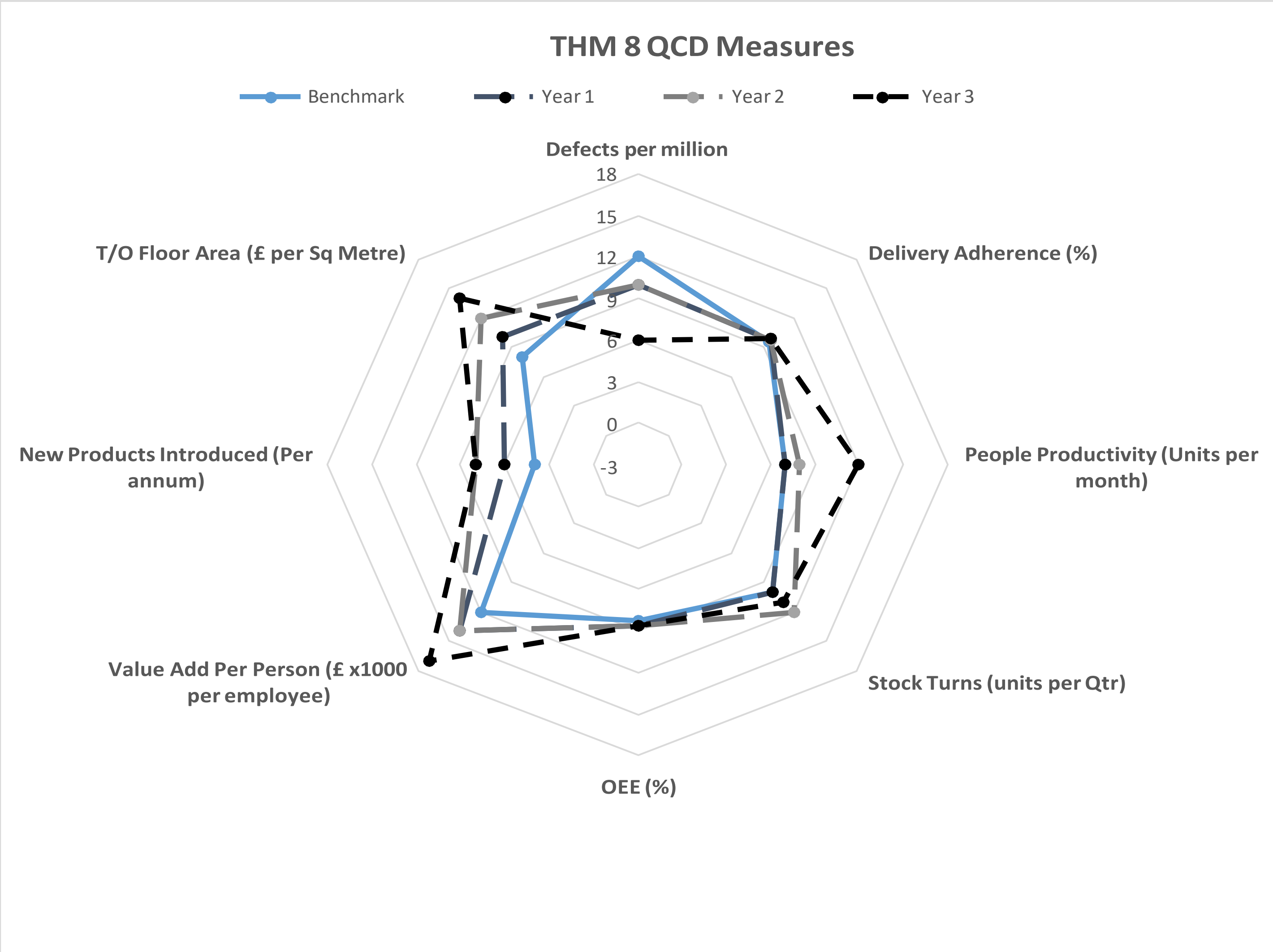

Figure 3 **The 8 QCD measures**