Beyond Lean: A Framework for Fit Production Systems

By

Oludare Adebayo-Williams

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GLOSSARY OF TERMS

AI	Agility Index
AM	Agile Manufacturing
AWM	Advance Warning Mechanism
AT&T	American Telephone & Telegraph Corporation
BMI	Body Mass Index
BERR	Department for Business, Enterprise and Regulatory Reform
DEC	Digital Equipment Corporation
DPU	Defect per Unit
EW	Elimination of Waste
EEF	Engineering Employers Federation
ES	Economic Sustainability
ESI	Economic Sustainability Index
FI	Fitness Index

GLOSSARY OF TERMS

FM	Fit Manufacturing
FPS	Fit Production System
FT	Financial Times
FTSE	Financial Times Stock Exchange Index
GE	Growth Efficiency
GM	General Motors
IP	Intellectual Properties
IW	Industry Week
JIT	Just-In-Time
LI	Leanness Index
LM	Lean Manufacturing
ME	Management Effectiveness
MTO	Make-to-Order
MTS	Make-to-Stock

GLOSSARY OF TERMS

MDNR	Michigan Department of Natural Resources
OEE	Overall Equipment Efficiency
OPF	Overall Production Fitness
OPFI	Overall Production Fitness Index
R&D	Research and Development
ROA	Return on Assets
PE	Profitability Efficiency
PFI	Production Fitness Index
SE	Survival Efficiency
SHRM	Strategic Human Management
SME	Small Medium Enterprise
SMED	Single Minute Exchange of Die
SI	Sustainability Index
TQM	Total Quality Management

GLOSSARY OF TERMS

UE	Utilisation Efficiency
QCD	Quality-Cost-Delivery
WIP	Work in Progress

Dedication

This work is dedicated to the glory of God and mankind. My special dedication goes to my father, Abraham Ayodele Williams, my sons, Justin Adesoji Williams and Anelka Adetokunbo Williams, and to Prof D. T. Pham who demonstrated the vision and the guidance in recommending me for a PhD programme when I did not conceive the dream. God bless you and your family.

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When I set out from my home country in 2001 to the UK, the dream was to develop myself and start a new life. I am therefore grateful to the Giver of life, the Omnipotent for protecting me this far, I am also grateful for all His divine interventions in my life. The achievement of my dream is an on-going project and I continue to look onto Him that makes all things possible to extend the breath and length of my life achievement beyond this height. Thank you Father.

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ABSTRACT

Western manufacturing companies are facing a challenging environment fraught with strong competition from India, China and other emerging economies. In this context, the effectiveness of the traditional production concepts of leanness and agility is being challenged. Against this background, the need for new manufacturing paradigms is set to provide new knowledge, techniques, and concepts useful for managers to address the difficulties of today's business environment.

This work extends the concept of production management beyond the achievement of efficiency short-term goals into the realms of strategic thinking by creating both the framework and the indices for an integrated production system. This research presents fit manufacturing as a new production model for a holistic manufacturing strategy that links the short-term goals of manufacturing effectiveness and efficiency embodied in lean and agile production strategies with the long-term objective of sustainable enterprise management. The research extends the concept of integration beyond ordinary manufacturing functions into the realms of strategic thinking.

The thesis gives an operational definition for the concept of fit manufacturing by describing the structural and operational characteristics of the production philosophy. It proposes the central theme of fit manufacturing as a manufacturing strategy essential to creating an integrated view of the factory – inside out and vice-versa. The idea of an overall fitness index combining measures of leanness, agility and economic sustainability is put forward and justified and the necessary conditions for fitness are derived. A case study showing an application of these different measures and the overall production fitness index is presented.

This research has shown that the fit production model combines the strengths of lean and agile manufacturing, with the long-term sustainability and viability of the enterprise. The model can be used to assess the performance of the production process, to evaluate investment proposals such as adding a new product line or increasing the overall capacity of the factory, and to build the enterprise of the future.

Keywords: Fit Manufacturing, Agile, Lean, Economic Sustainability, Integration, Fitness

CHAPTER 1

INTRODUCTION

…"competitive landscape for manufacturing is undergoing a transformational shift that will reshape the drivers of economic growth, wealth creation, national prosperity, and national security. "

Deloitte & Council (2010)

1.1. Preamble

In the face of stiff competition in the market place especially from the low cost producing countries such as China and India, manufacturing companies in western economies are increasingly adopting different manufacturing paradigms to help their continued survival. These manufacturing methodologies or continuous improvement themes help organisations to characterise their current operational efficiencies with a view to increasing company performance, market share, profitability and product quality. Such manufacturing methodology includes six sigma, lean manufacturing and agile manufacturing. Each of the methodologies tends to revolutionise the organisation performance by configuring the operational strategies to meet specific requirements while delivery shot-term bottom-line savings (Pham et. al., 2011).

However, the post-industrial manufacturing system of the 21st century goes beyond the ideas of efficient production of goods and services but is characterised by increased market diversity and complexities, rapid technological change, and world-wide spread of advanced manufacturing technologies (Doll, 1991). The globalisation of manufacturing systems implicitly implied managers of manufacturing firms must now place emphasis on total manufacturing systems developments (Browne et al., 1995). This requirement has fostered stiff competition in the market place and continues to force organisations to reinvent and to re-invigorate business strategy in order to prosper and stay ahead of changes in the operational environment.

This increasing complexity of the business environment implies organisations have to be able to compete not only on the basis of the traditional production factors of cost, material and labour but on some other criteria that confers leanness, agility, adaptability and economic sustainability. This radical change in the manufacturing industry landscape calls for new strategic thinking that guides and assesses organisational capabilities to integrate both adaptive and proactive competitiveness in order to realise economic sustainability. Hence, the traditional approach of the industrial value chain, which advocates strategies that enables firms to achieve efficient and effective positions in that value chain, rather than re-inventing and changing the configuration of the value creating system, is being called to question.

For instance, despite a reported greater take-up of lean manufacturing by many companies in the UK (EEF, 2001), the manufacturing sector continues to witness a steady decline (Pham et. al., 2011). Perhaps this is because lean and agile manufacturing are fundamentally restrictive in scope. These strategies are structured to help manufacturing companies to face increasingly intense competition by improving their productivity which, although a requirement for a long-term future, is not, on its own a sufficient condition for economic sustainability. For instance, lean production in its purest form focuses on how to use a pull system (kanban) to respond to customer requirements (Bunce, 2003). While such a system might be efficient at manufacturing products wanted by the market, it cannot anticipate changes in customer requirements or the need to adjust product offerings to, or ahead of, those changes.

This means that manufacturing companies will have to go beyond cost-cutting strategies and adopt a holistic manufacturing model. The holistic manufacturing model must also offer the diverse groups of stakeholders a better guarantee of sustainable prosperity rather than in the past, when stock-market returns were used as the primary measurement of management performance and the well-being of the firm (Lohr, 2009). Accordingly, manufacturing firms should look beyond the achievement of the company’s goals of quality, reduced operational costs and reduced time to market, to how they can organise and manage their activities in order to achieve long-term competitiveness. In the post-great depression economy, the attainment of leanness and agility goals for any company is considered a basic requirement in order for the company to survive. Hence, managers of firms must rethink their strategies of towards becoming ‘lean, agile and fit’ (Pham et al., 2008).

There are a number of existing fitness theories for understanding organisational development and firm dynamics (Wright, 1932; Kauffman and MacReady, 1995; Levinthal, 1996; Beinhocker, 1999; Barnett and Sorenson, 2002; McCarthy, 2004). However, this work aims to explore the development of a holistic manufacturing paradigm, called fit manufacturing, as the basis of creating sustainable economic value and realising organisational long-term fitness. In addition, fit manufacturing is being advanced as a manufacturing strategy for achieving continuous organisational survival and economic sustainability. Fit manufacturing places new set of expectations on manufacturing firms to be managed and run with a focus on economic sustainability rather than the pursuit of unlimited year-in year-out short-term growth strategy. This paradigm shift for some managers of manufacturing firms means sustaining the current systems, structure and ways of life; for other it means a radical re-order of their business model in ways that may facilitate broader changes towards a more economically sustainable future.

Consequently, fit manufacturing is seen as company-wide strategy that enables organisations to manage the complexity of the market place, consumer expectations in terms of products and prices, waste elimination in processes, adaptation of production capacities to meet new products designs challenges, market fluctuations and supply chain management. Fit manufacturing is able to assist organisations to remain agile and sustainable through a strategic approach that places emphasis on skilled and motivated workforce, use of advance computer technologies and flexible organisational structure.

1.2 Motivation for the Study

Lean and agile manufacturing are two process and productivity improvement strategies, which have been introduced as manufacturing paradigms that help manufacturing firms to respond to the challenges of 21st century Womack et al (1990), Kidd (1994). Since their introduction, the manufacturing initiatives continue to enjoy an increasing uptake especially in the UK and U.S and dominate the attention of the academia, policy makers, business managers and practitioners of diverse opinion. For instance, in a census of U.S. manufacturers conducted by IndustryWeek (IW) / Manufacturing Performance Institute (MPI), it was reported that in 2007 nearly 70 percent of all plants in the U.S. were employing lean manufacturing as an improvement methodology; in 2006 this figure was 40.5 percent while in 2005 the number of U.S. plants reported to be implementing lean manufacturing was 35.7 percent Blanchard (2007). In the UK, report shows that while lean manufacturing concept continues to engage the attention of UK manufacturers, they do not pursue it with the same intensity and depth compared to U.S. firms EEF (2001).

Despite the frenzy of activities associated with the uptake of lean manufacturing, the IW/MPI survey also reveals that success rate with lean implementation is quite limited Pay (2008). An example of works which question the effectiveness of lean manufacturing is the work of Dan Coffey (2006).

Coffey (2006) argued that unlike what is widely proclaimed by the academic, literatures, policy makers and commentaries, lean manufacturing did not herald in any radical changes in the world's car manufacturing and assembly sector because "its terms are more obviously myth". Based on data collected by the author on factory visit, the author also broach on the BMW-Rover Group controversy as an example of the failure of just-in-time production. The defunct British car plant was in the 1980s in a collaboration with the Japanese firm, Honda. The author provided empirical evidences that suggest that the criterion for survival extend beyond the implementation of lean manufacturing, and by extension any improvement programme including agile.

Various works have tried to examine the concept of corporate survival and longevity. Each of these works adopted different approaches to investigate the common characteristics of long-term survival and whether "corporate existence is simply a matter of following an ageing process to an inevitable end or is there a secret of survival". For instance De Geus (1999) hypothesized that the average life expectancy of a multinational corporation-Fortune 500 firms or its equivalent is between 40 to 50 years. Caulkin (1995) noted that as at 1995 only nine of the original 30 constituents of the FT Ordinary Share Index in 1935 survived, while Mackey and Valikangas (2004) asserted that among the companies on the original *Forbes 100* in 1917, 18 remained in the top by 1987 and 61 had ceased to exist. In addition, Hamel and Valikangas (2003) commented that in the past two decades, of the 20 largest US companies' bankruptcies, ten occurred between a period of two years, 2000 to 2002.

From the foregoing it is clear that achieving longevity goes beyond the implementation of lean and agile improvement programme. Operational excellence remains a key in competition but not enough to build fundamentals that lead to creating enduring firms, more so, achieving corporate longevity and economic sustainability is a major focus for managers in manufacturing firms. The implementation of lean and agile initiatives has not really facilitated an organisation's long-term economic sustainability because these manufacturing initiatives in their pure forms are improvement programmes and are inadequate to meet the challenges of sustainable future (Pham et al., 2011).

The economic sustainability credentials of these improvement programmes are not helped either by the foreclosure of manufacturing companies who have tried to improve their productivity, competitiveness and hence economic sustainability using these initiatives. The issue for many organisations is that these proposed solutions, although they deliver economic benefits in the short-term, failed as long-term business improvement strategies since they rarely become the explicit or even implicit focus of change initiatives in companies (Bateman, 2001). It clear that the manufacturing industry requires a "total" manufacturing initiative that is pro-active to market changes and capable of delivering both short-term operational goals and long-term suitability benefits. This integrated manufacturing strategy, called *Fit Manufacturing*, is defined as the integration of three major business process priorities: "Leanness", "Agility", and "Sustainability" (Thomas and Pham, 2004). Consequently, an enterprise can be said to be fit if it exhibits the general principles of agility and leanness such that its business strategy, core values, organisational structure, human resource policies, IT infrastructure and leadership style are sustainable in accordance with changing patterns of market demands.

1.3. Research Agenda

Under the fit manufacturing framework, a manufacturing firm is said to be fit, if its operational strategy can be described as lean, agile and sustainable. Each of the three core elements brings different perspective to the world of manufacturing fitness.

- Lean is a business improvement strategy that focuses on eliminating waste, improving process flow and value adding activities (Womack and Jones, 1996). Waste is anything done that does not contribute to meeting business requirements. Lean approach to process improvement is horizontal as the approach focus across the process to understand requirements and eliminate waste.

- Agility focuses on operational adaptability, the ability to response to irregular demand patterns in real time so as to meet customer expectations. Agility allows companies greater flexibility in responding to market changes and providing personalised products and services at mass production prices. The approach is cross-functional and hinge on effective use of information in order to respond swiftly to changing demands.

- Economic Sustainability focuses on the dynamics of business perpetuation and survival through the ability to apply lean and agile strategies so as to ensure that current operational strategies meet present challenges without compromising the ability to meet future manufacturing challenges. The manufacturing initiative ensures that efficiency and productivity are sustainable in the face of stiff competition and changing demand.

Each of these three core elements of fit manufacturing has their unique strengths that make them most appropriate for achieving certain competitive priorities. However, research in manufacturing strategy provide two different models that describe the relationship between competitive priorities; these are the traditional trade-off model and the cumulative model (Boyer and Lewis, 2007). Boyer and Pagell (2000) suggested that the degree of fit between an organisation's competitive priorities and its key decisions regarding structural and infrastructural investment provides the key to developing the full potential of operations as a competitive weapon.

Commonly agreed key competitive priorities are cost, quality, flexibility and delivery (Anderson et., 1989; Leong et al., 1990). Fit therefore represents the outcome of the effectiveness and consistency of the degree of integration of a manufacturing firm's key competitive priorities with the goals of economic sustainability.

Nevertheless, a major requirement for achieving an integrated manufacturing strategy is the measurement methodology. Ebrahim (2011) argued that analysing production capabilities from a fitness perspective requires determination of fitness components and fitness measures. More so, there is no commonly agreed operational performance measure developed for integrated manufacturing systems. Most of the developed performance measurement models are designed for measuring isolated capability, such as: Leanness (Bayou and de Korvin, 2008; Ray et. al., 2006; Wan and Chen, 2008); Agility (Bottani 2009; Shih and Lin, 2002; Tsourveloudis and Valavanis, 2002); Flexibility (Bateman, et al., 1999; Wahab, 2005; Wahab and Stoyan, 2008), Responsiveness (Kritchanchai, 2004; Matson and McFarlane, 1999), and

Sustainability (Calvo, et al., 2008; de Vos et al., 2006; Singh, et al., 2007).

1.4. Research Questions

The trend towards a holistic manufacturing framework places further burden on companies and therefore an integrated manufacturing approach must be developed in order to ensure that the factory of the future is able to meet this new demand (Pham and Thomas, 2012).

The quest for a holistic manufacturing framework gives rise to the following research questions in relation to the development of fit manufacturing strategy: (i) What is the intrinsic nature of Competitive Fitness (ii) How can the efficiency of an Integrated Production System be evaluated? (iii) What are the necessary conditions for Integrated Production System? The first research question is important in identifying the physical aspect of the phenomena called fit. The second research question is useful in identifying how to monitor and measure indicators of integrated production system; while the third research question focuses on identifying, fostering and encouraging the enabling conditions for integrated production system. The fit manufacturing strategy this work expounds differs from the concept of fitness landscape. The theory fitness landscape makes use of mathematical models to investigate evolutionary fitness within the competitive landscape (McCarthy, 2004). The theory examines how manufacturing companies imitate successful firms and adapt in order to compete and survive. It is important to note that the fit manufacturing strategy expressed in this work evaluates the competitive ability of the production system along the dimensions of leanness, agility and sustainability.

1.5. Research Hypothesis

(a) It is assumed that over a period of time fitness outcomes take the shape of an “S Curve” when depicted graphically. This statement implies fitness is a function of time and not an end state. Hence, is it assumed that the operation of a manufacturing firm continually generates new fitness scores against which its long term economic sustainability is assessed. This helps the organisation to evaluate its future prospects of survival.

(b) The slope of the fitness curve for a company indicates whether its fitness level is increasing, decreasing or static. A negative slope signals a decline in the overall health of the business. If this were to persist, it would eventually lead to failure of the company.

(c) From the statement above it follows that: a fit system is one which, when subjected to a step change or continuous change induced internally or externally, is able to cope with the change and adjust itself overtime without suffering a sustained declined which could lead to a total failure. Fitness Index (FI) is therefore defined as the output of a manufacturing company against leanness, agile and sustainability performance enablers.

1.6. Research Aims and Objectives

This research aims to provide a theoretical framework for the development of fit manufacturing in order to answer the research questions. The theoretical framework for fit manufacturing is based on the hypothesis that manufacturing firms can compete, remain successful and prosper in a dynamic and ever changing business environment through the integration of the efficiencies strategies with the long-term objective of business longevity.

The aims and objectives of the thesis are therefore to develop a model for an integrated production system called fit manufacturing, and also contribute to the definition of fitness within the context of production management. This aim necessitated the investigation of lean production features, agile manufacturing features, and economic sustainability using accounts presented in literature. This investigative approach was considered to contribute more to the development of a holistic integrated production model rather than the alternative route of independent investigation of these production models. More so, the literature on lean and agile manufacturing strategies are quite advanced and well documented. A further aim of the research was to provide an objective performance measure of fitness index.

In order to achieve the stated research aims, the following objectives are set:

i. Clarify the three stated dimensions of the fit Manufacturing initiative, namely: Leanness, Agility, and Economic Sustainability

ii. Within the context of the fit Manufacturing initiative, develop an index each for Leanness, Agility, and Economic Sustainability

iii. Determine the intrinsic nature of fitness within the context of Fit Manufacturing initiative

iv. Based on the three core components of Fit Manufacturing, develop a methodology for assessing Fitness Index (FI)

v. Determine the necessary conditions for fitness within the context of Fit Manufacturing initiative

1.7. Premises and Delimitations (Research Scope)

Premises form the basis upon which this research rests. Delimitations define the scope of the research.

1.7.1. Premises

- There is little formal research and evidence from industry to substantiate the value of fit manufacturing algorithm.

- There is no universally agreed approach to measure Leanness, Agility, and Economic Sustainability

- The continued rapid growth in the body of knowledge on economic sustainability will challenge managers and practitioners to identify and extract relevant knowledge and apply it to the development of sustainable factories of the future

- Existing business improvement strategies have not addressed tasks related to manufacturing fitness and economic sustainability

- This research assumes that the use of case study data as subjects is generalisable to the development of fit manufacturing

- This research assumes that data from the case study companies is representative of manufacturing process, procedures and tasks in industry

1.7.2. Delimitations

- This research focuses on the development of fitness measures for production operations using data gathered from case study companies implementing batch processing.

- In order to determine the fitness measures, data are from the beginning of the manufacturing process (raw material preparation) to the end of the manufacturing process (delivery packaging process). Thus, the fitness measures consider production capacity that is generated by internal resources only.

- This research will not consider other business improvement strategies outside lean and agile manufacturing strategies

- This research will assumes that the production process at the level researched herein is generalisable to more complex products and systems

1.8 Research Method

This constitutes the practical steps and the path applied in this thesis to finding answers to the research questions. Dawson, 2002; Kumar, 2005; and Kothari, 1985 suggested that research methodology represents the scientific strategy - *methods, procedures* and *models* – the research implemented in achieving the research objectives. Research methods consist of systematic observation, classification and interpretation of data to solve the research problem and create new acceptable knowledge. The research procedures consist of appropriate logical sequence, and relevant methods and techniques that have been tested for their validity and reliability. The research models consist of a multiplicity of approach, within a framework of a set of philosophies - including qualitative and quantitative methods (Wass and Wells, 1994).

The research methodology implemented in this thesis consist of a multi-method approach, which is seen as common to research of complex phenomena (Easterby-Smith et al., 2002). The thesis focuses on the development of fitness measures for production operations, specifically the batch process type for the production of semi-finished goods and finished consumer goods. Due to the nature of the research problem, the research methodology implemented draws upon quantitative and case-study methods; and the research procedure follows similar path implemented by Ebrahim (2011). This offers the opportunity to compare the research findings with existing body of knowledge*, what is already known*, within the context of fit manufacturing.

The thesis research methodology comprises six stages:

i. Conduct literature review to clarify the nature of leanness, agility, and economic sustainability within the context of fit production system

ii. Within the framework of fit manufacturing, suggest new and easier to implement measures and methods that can be utilised to examine and analyse leanness, agility, economic sustainability, and the fitness of production operation

iii. Develop measures and methods for assessing the performance of fit production system

iv. Validate the research hypothesis using data from case studies

v. Identify the necessary conditions for fitness

vi. Identify the factors influencing fit production system from the aspect of a company manufacturing operation and production characteristics

1.8.1 Case Study Methodology

Given the nature of the research question on the domain of the research problem, it is evident that objective data are necessary in order to develop fitness measures. This implies the empirical data required to validate the research hypothesis and the research theory can only be collected by applying case study method. Consequently, in order to achieve the research objectives data from six case study companies were examined and analyses. The use of case study method enables the researcher to provide systematic way of looking at events, collecting data, analysing information and reporting results (George and Bennett, 2005). Case study methodology also was considered because the method can be used to investigate a contemporary phenomenon within its real-life context, when boundaries between phenomenon and context are not clearly evident. This also allows for multiple sources of evidence to be investigated (Stake, 1995; Yin, 2003).

1.8.2 Sample Size and Limitations

Within the context of the thesis, the main strengths of using case study methodology are the broad coverage of all the production subsystems that can be examined for data collection ensuring that findings are validated and triangulated to provide conclusive evidence. The main weaknesses of the research approach are the limitations of sample size and depth which is a direct consequence of the holistic approach pursued in this study.

The five years historical data utilised for testing the research hypothesis were collected from six companies out of a total of initial 35 selected to participate in the inquiry. Some of the archival data required were not available and were constructed using other relevant data. The data were collected primarily using interviews, observations, and archival sources (Ebrahim, 2011).

1.8.3 Method of Analysis

Microsoft Excel Software was used to analyse the case study data. This software was selected because of its ability to integrate and handle spreadsheet data. In addition, Excel handles data analysis quite well in the context of process improvement and project management. Results of the analysis were plotted using Excel tables and graphs functions.

1.9 Structure of the Thesis

The thesis is divided into six chapters each focusing on specific research objective that contribute to the overall report conclusions and findings. The thesis structure is laid out as follow:

- Chapter one presents the background and the main research questions together with the motivation for the study, including a short overview of the research methodology

- Chapter two presents the conducted literature review. Previous work and the state of art on the three components of fit manufacturing, namely, lean manufacturing, agile manufacturing, and economic sustainability are reviewed. The chapter also reviewed the evolution of integrated manufacturing system, and presents a justification for fit manufacturing as a concept for integrated production management.

- Chapter three provides an operational definition for the concept of fit manufacturing by describing the structural and operational characteristics of the production philosophy. The chapter expands the central theme of fit manufacturing as a manufacturing strategy essential to creating an integrated view of the factory – inside out and vice-versa. The idea of a fitness index is presented and justified. Groundwork for subsequent development and evaluation of indexes for each of the three components of fit manufacturing – leanness, agility, and sustainability – is discussed.

- Chapter four presents the theoretical constructs for measures of integrated production system. The chapter discusses and implements the concepts of leanness index, agility index, and economic sustainability index. The lean index presented assesses a production system's efficiency at producing quality goods, waste elimination, and sales optimisation. The agility index evaluates the efficiency of the production system flexibility (product range) against responsiveness (changeover time) to unpredictable changes in the market place, while the sustainability index evaluates the firm's performance against five defined dimensions of sustainable performance.

- Chapter five discusses the research results and analysis. Evaluation of fit production system and the application of the three indexes of leanness, agility, and sustainability to the case study data is discussed. From the results of the analysis, the novel overall production fitness index (OPFI) is developed and justified, and the research hypothesis validated. Necessary conditions for fitness are presented.

- Chapter six presents the research contributions, conclusions, and future work recommendations.

CHAPTER 2

LITERATURE REVIEW

…"different production 'systems' have different operating characteristic and each involves a different set of trade-offs…some will be particularly good at producing standardised products in high volume at low cost, others will excel at responding quickly to shifting demand for more customised products. " Skinner (1969)

2.1. Preamble

This chapter reviews the three components of fit manufacturing, namely, lean manufacturing, agile manufacturing, and economic sustainability. The chapter also reviews the evolution of integrated manufacturing system, and presents a justification for fit manufacturing as a concept for integrated production management.

In the first section, the evolution of manufacturing systems is discussed starting with craft production system to integrated production manufacturing strategy. An attempt is also made to review the key difference between lean and agile manufacturing and clarify the areas of overlaps between these two manufacturing strategies. The third section of the literature review discusses economic sustainability from the perspective of integrated manufacturing strategy. The concept of fit manufacturing is proposed and its justification presented.

2.2. Craft Production System

At the beginning of the 20th century, craft production was the dominant production system. This was the manufacturing technique used in the pre-industrialised world. The innovations of sixteenth, seventeenth, and eighteenth centuries were possible through the use of machine tools developed from craftsmanship. For example standardised craft production was used in the business of clock making (Ehrenreich, 1991; Boorstin, 1983). Hence, giving the pioneering nature of the production system, its study extends beyond the sphere of manufacturing into areas of ecology, material culture, economic organisation, political economy, and exchange (Costin, 2007; Camillo, 1997; Brumfiel and Earle, 1987). However, for the purpose of this work; the concept of craft production system is examined mainly within the context of manufacturing.

Craft production system is characterised by use of craft-based skills in small-scale factories operated as ‘jobbing shops’. The production system was co-ordinated by wealthy entrepreneurs who were responsible for organising highly specialised networks of customers, employees, and parts suppliers. Manufacturing using craft production meant production volumes were low, the customer base was low, and the products were expensive. Craft production required a work force that was highly skilled in design, machine operations, fitting, and precision engineering. The production system is noted for its ability to produce customised products. Under craft production system, work organisation was decentralised, precision machines tools were utilised to help standardise the production technique in order to ensure uniformity of design (Howleg, 2002; Womack et al., 1990; Altshuler et al. 1984). Figure 2.1 illustrates elements of craft production system.

Products manufactured using craft specialisation are usually seen to be of high quality and refinement. It is therefore possible to argue that originators of craftsmanship were perfectionist, interested in making things as unique as possible. However, goods produced this way were usually affordable only by the rich. This is especially true in early automobiles that were craft produced. Each vehicle was unique, and replacement parts had to be manufactured from scratch to fit a specific vehicle. For example, in the early part of 20th century, Etorre Bugatti built racing cars and luxury road cars using craftsmanship. The small number of cars means they could not be afforded by people on modest income, eventually these cars became the mainstay of European motor racing between 1926 and 1931(Wood, 2007).

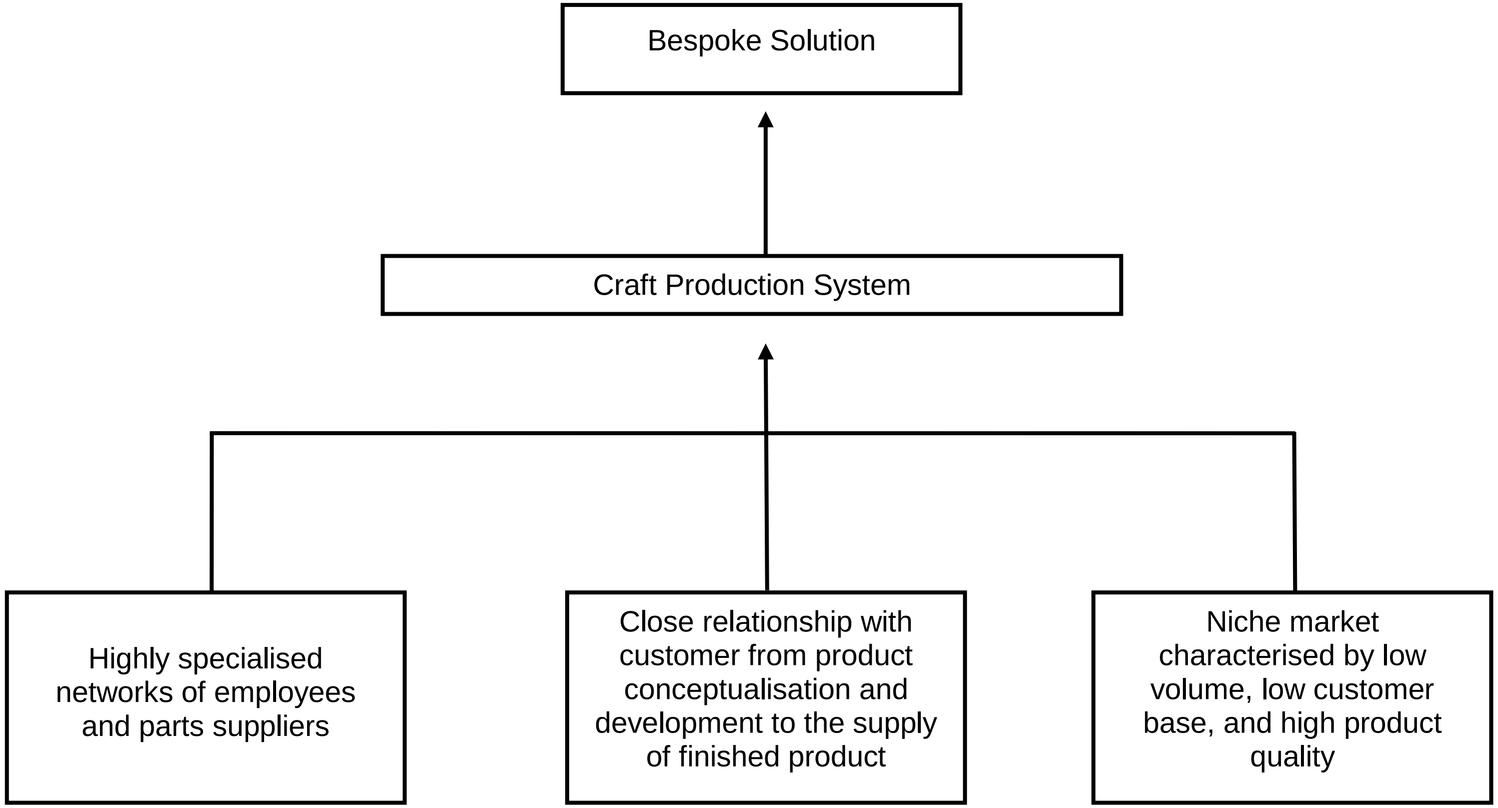


Figure 2.1: Elements of craft production system

While product uniqueness can add value to a product’s overall appeal and distinctiveness, uniqueness can also be disadvantageous because of replacement part compatibility (Womack et al., 1990). This is the fundamental benefit of standardisation and mass production, to make quality products with interchangeable parts available to people of all income level. The change in focus from craftsmanship to mass production, also enable the development of mechanised production technology. By the end of World War I (WWI), mass production was being embraced by large scale manufacturers especially of books and newspapers. The production system was the production of choice to achieve greater efficiency, less waste, and by extension, greater production volume (Clair, 1976).

2.3. Mass Production System

By the early 20th Century, the production of standardised goods for a mass market was on the rise in the United States, enabling the transformation of the industry. The first industrialist to make full use of this system was Henry Ford and as a result mass production of standardised goods became known as Fordism (Foner, 2006; Holden, 2005; Doray, 1988; Tolliday and Zeitlin, 1987). This production method makes use of dedicated machines and moving assembly lines, unskilled and semi-skilled labour who worked on an individual step of the production process in large factories. The rise of mass production system propels the growth of mechanisation and the development of factories for the advancement of the society towards specialisation (Hindle, 2002; Price, 2004). Specialisation not only enables greater efficiency for manufacturing, but also a tendency towards reductionism (Manson and Halsey, 2011). The mass production method enabled Ford Motor Company to reduce the hours it took to assemble a Model T car from the initial 14hours to 1hour 33minutes. This lowered the overall cost of each car and enabled Ford to reduce the selling price of the Model T from $850 to $260 (Ford Motor Company, 2012; Hounshell, 1984).

It is important to note that the mass production system incorporates principles of scientific management as promulgated by Fredrick Taylor and his disciples (Doray, 1988). Mass production paradigm places emphasis on mass markets, standardised designs, and high volume production of standard products creating economies of scale (Altshuler et al. 1984). The concept of mass production is inextricably linked to inter-changeable parts, use of electric motors to line assembly, use of inventories to buffer different stages of the production process, machine automation, and organisation of work in a logical sequence under tight supervision (Hounshell, 1984). The success of this production paradigm helped the United States become an industrial powerhouse by the 1920s, and also revolutionised the way other manufacturers produced cheap goods (Hayes and Pisano, 1994; Smil, 2005; Chandler, 1977). Figure 2.2 is an illustration of mass production system.

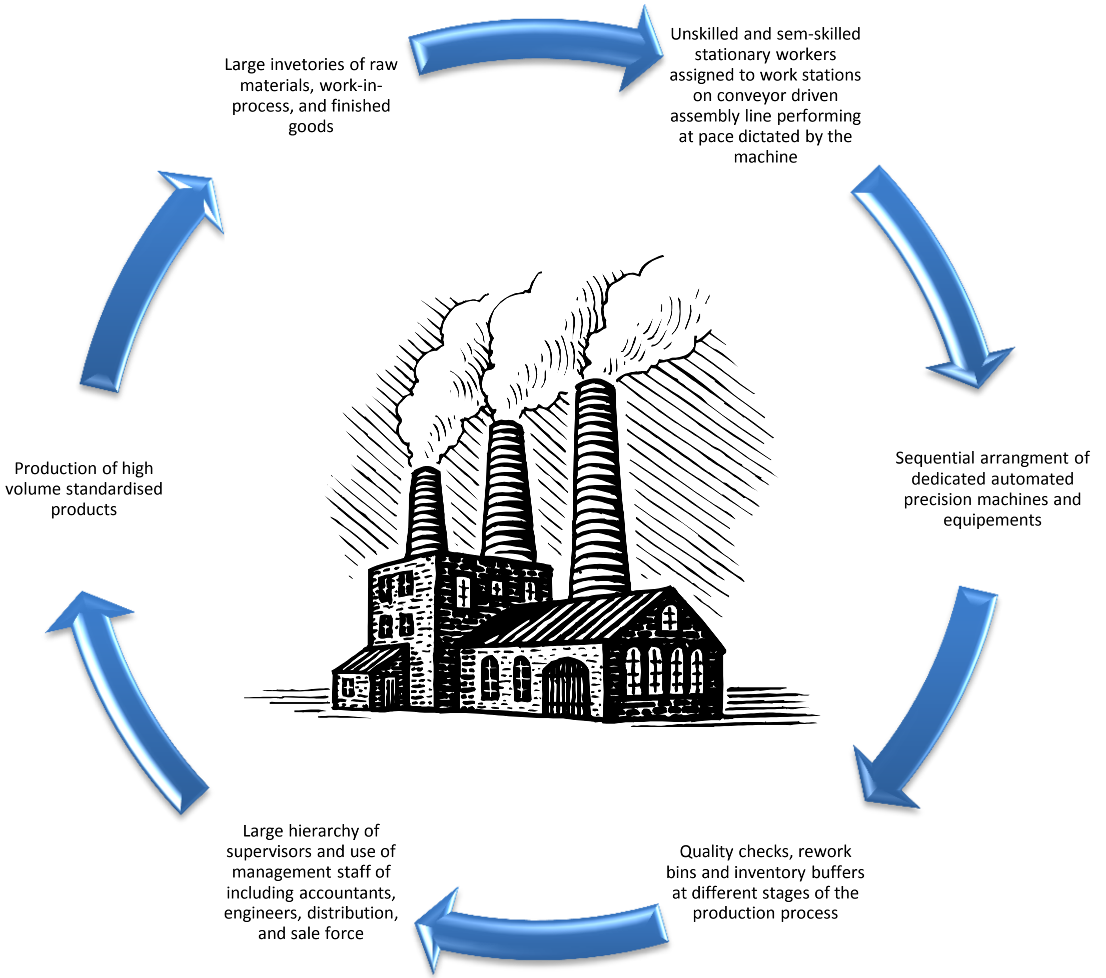


Figure 2.2: Elements of mass production system

2.3.1. Advancement in Mass Production

The advancement of mass production enabled Ford Motor Company to generate mass consumption through the manufacture of cheap, robust, easy-to-repair vehicles (Howleg, 2002). By mid 1920s, the mass production of the Model T enabled the automobile outputs of the US to overshadow that of European producers and other global vehicle manufacturers. The introduction of the Model T also revolutionised transportation and American industry (Tolliday and Zeitlin, 1987). To improve the production process, Ford experimented with industrial engineering practices, streamlined the production process, and introduced automation to auto production. This era also witnessed the introduction of conveyor-driven flow production, use of standardised interchangeable components, few suppliers, lack of product variety, and the simplicity of the product in assembly. These innovations enabled Ford to achieve the 'universal car' concept (Womack et al.1990; Ford, 1922). Though, some of these practices were not necessary new innovations but influences from the scientific management theory (Clark, 1990; Axelrod, 1984; Abertnathy et al. 1983). However, a Ford assembly line was seen as dirty and dangerous place to work and many contended that mass production created only boring and monotonous tasks (Baldwin, 2001). In defending the assembly line, Henry Ford sated that (Ford, 1928)

> *“It has been asserted that machine production kills the creative ability of the craftsman. This is not true. The machine demands that the man be its master; it compels mastery more than the old methods did”.*
>
> *The number of skilled craftsmen in proportion to the working population has greatly increased under the conditions brought by the machine. They get better wages and more leisure in which to exercise their creative faculties*”.

2.3.2 Decline of Mass Production

As the market for automobiles expanded during the 1920s, weaknesses of Ford single product dedicated production facilities began to emerge. The company’s inability to respond to market sensitivity and offer consumers increased products variety would later cause problems for the company and brought the firm’s dominant market position under attack from other mass producers, most importantly General Motors (GM) (Howleg, 2002; Womack et al.1990). Unlike the mass production system of Ford, GM mass production system, as designed by Alfred P. Sloan, involved the use of standardised components shared by many vehicles, holding high inventories (Chandler, 1962**)**, and use of sub-contracting rather than vertical integration as practiced by Ford. Other innovative concepts introduced by GM from the 1920s through the 1950s included annual model roll out through the concept of planned obsolescence (Bulow, 1986; London, 1932), broad product line, diversified mass marketing, automotive design (styling), and centralised decision making system. These concepts among other management techniques, programs, and infrastructure helped GM achieve automobile industry leadership by 1930s. By this time, GM concept of producing ‘a car for every purse and purpose’ has displaced Ford’s ‘universal car’ concept (Sloan, 1964; Ford, 1922). GM flexible production system changed mass production system, structure, and management practices forever (Pelfrey, 2006; Meyer, 1989).

However, a major problem that led to the decline of GM mass production system is the centralisation of coordination and administrative functions to a general office. The general office was responsible for organising an authoritative system for projecting demand, parts and material purchasing, production and inventory control, product engineering, and marketing. By putting in place a centralised structure to coordinate the different brand divisions, GM effectively restricted the ability of the product divisions to make strategic decisions outside of manufacturing operations. This eventually means GM was producing and running differentiated and diversified lines of cars using a centralised strategy which effectively limited its ability to respond to market fluctuations and shift in demand profile. For instance, decision involving planning of repair parts production was not left to the Buick division but was made at the centralised general office which also made similar decision on behalf of the other brands. Similarly, costing and profit accounting standards, calculation of investment returns, divisional supplier relations, and other investment strategy were centralised. (Waddell, and Bodek, 2005; Chandler, 1977; Drucker, 1946).

2.4. Lean Production System

From the mid -1970s, changes in markets demography and technology continued to transform competitive conditions and spurred manufacturers across the globe to experiment with new manufacturing strategies based on greater product diversity and more flexible methods of production (Tolliday and Zeitlin, 1987). The preceding decades also witnessed increased importation of cars from European manufacturers into the U.S market, and by 1956, GM's market share for new car sales in the U.S. fell to 42 percent (Chandler, 1977).

The improvements in technique, organisation, and mechanisation of production also gave rise to environmental demand of less polluting cars. Moreover by 1974, GM was spending $2.25 billion to meet pollution regulations with that figure doubling at the end of the decade. By early 1980s, the demand for less pollution opened the way for Japanese manufacturers to gain a foothold on the U.S. market through the introduction of reliable, smaller, competitively priced cars (Chandler, 1977). The Japanese manufacturing approach emphasise attaining competitiveness through the improvement of a variety of production activities. These new manufacturing approaches enable Japanese companies to surpass their Western counterparts across several manufacturing dimensions at once and achieve cost advantage. These Japanese manufacturing philosophies and techniques included total quality management (TQM), supply chain management, just-in-time (JIT) production, re-engineering, bench marking, high level of employee problem-solving and involvement, the kanban method of pull production and so on. These manufacturing practices for improving productivity and competitiveness are commonly known as dimensions of lean manufacturing. By mid-1990s Western companies had adopted and adapted many lean practices and the concept was extended from production to the whole enterprise (Hines, et al., 2004; Hayes and Pisano, 2000; Bicheno, et al., 1997).

2.4.1 Relationship between Lean Manufacturing and Toyota Production System (TPS)

Many of the lean manufacturing practices have their roots in Japanese vehicle industry. More so, the term "*lean*", or "*lean production*", or "lean manufacturing", was coined by the book *The Machine that Changed the World*. The lean book gives an account of Toyota Production System (TPS) and highlighted the performance gap between Toyota and other carmakers (Womack et al.1990). TPS or lean manufacturing was hailed as the source of Toyota's outstanding performance as a manufacturer because the production philosophy was seen to produce more with less time, inventory, capitals, and fewer resources (Womack et al.1990; Spear and Bowen, 1999). Many lean practices, systems, and methods resulted from Toyota's effort to respond to intense domestic competition in the Japanese market for automobiles given limited resources. The development of Toyota Production System, or lean manufacturing, is usually credited to four prominent people within the Toyota Corporation:

Sakichi Toyoda, the founder of the Toyoda Group in 1902 is usually credited with the development of the principles of 5 Whys, and the concept of Jidoka. This concept, also referred to as “automation with a human touch” (visual management), whereby if an equipment malfunction or a defective part is discovered, the machine stops itself immediately, the operator ceases production and takes corrective action preventing defective products from being produced. Jidoka also means a machine safely stops when the normal processing is completed. The state of the machine is communicated via “andon” (problem display board). This means an operator can be assigned to many machines to monitor their operations resulting in higher productivity through effective utilisation of manpower resources (Becker, 1998).

Kiichiro Toyoda, son of Sakichi Toyoda, who headed the automobile manufacturing operation between 1936 and 1950; developed the concept of Just-in-Time (JIT). The basic philosophy is Just-in-time is to ensure that each process produces only what is needed, just in time and not too early or too late, by the next process in a continuous flow (Womack et al.1990). Later elements developed and added to JIT concept included takt time, standardized work, kanban, and supermarkets (TPS Handbook; Becker, 1998).

Eji Toyoda, cousin of Kiichiro Toyoda, was the Managing Director of Toyota Motor between 1950 and 1981 and Chairman between 1981 and 1994. Eji Toyoda is credited with the development of continuous improvement (kaizen), an improvement of Ford's employee suggestion system. A qualitative process learnt during his trip to Ford Motor Company in 1950 (Dawson, 2004; Becker, 1998).

Taiichi Ohno, is largely considered the father of Toyota Production System. He oversaw the task of devising means to improve operational productivity and waste reduction. Many of the different tools and techniques associated with TPS including the seven waste principles, the kanban system, setup time reduction (a.k.a. rapid changeover) also called single minute exchange of die (SMED), machine layout, multi-function worker, work standardisation and minimal in-process inventory, were devised by him. He underlined the company's waste elimination philosophy as the emphasis on increasing productivity and reduced cost. The approach was to investigate one by one the causes of all kinds of un-necessary functions in manufacturing operations and devise methods for their solutions, through investigative approach of trial and error (Ohno, 1988).

According to Becker (1998) two other notable people that helped developed the Toyota Production System were Shigeo Shingo and Edward Deming. Shigeo Shingo is credited with the development of a number of quality tools and techniques including principles of zero defects and Poka-yoke (mistake-proofing), while Edward Deming is credited with the introduction of Statistical Process Control to Japan.

Figure 2.3 is a graphical representation of Toyota Production System taken from the TPS Handbook. The diagram explains the key concepts and tools associated with the production system. These innovative concepts and practices form the **‘***core of lean manufacturing’***.** A lean production model can therefore be described as a multi-dimensional approach designed to synergistically creates a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste (Shah and Ward, 2003). Essentially, lean manufacturing (LM) observes the process from the customer point of view and eliminates waste in an effort to achieve perfection (Mandahawi, et al., 2012). When the lean model is contrasted with alternative model of mass production, lean methods, processes and techniques are less capital intensive to implement.

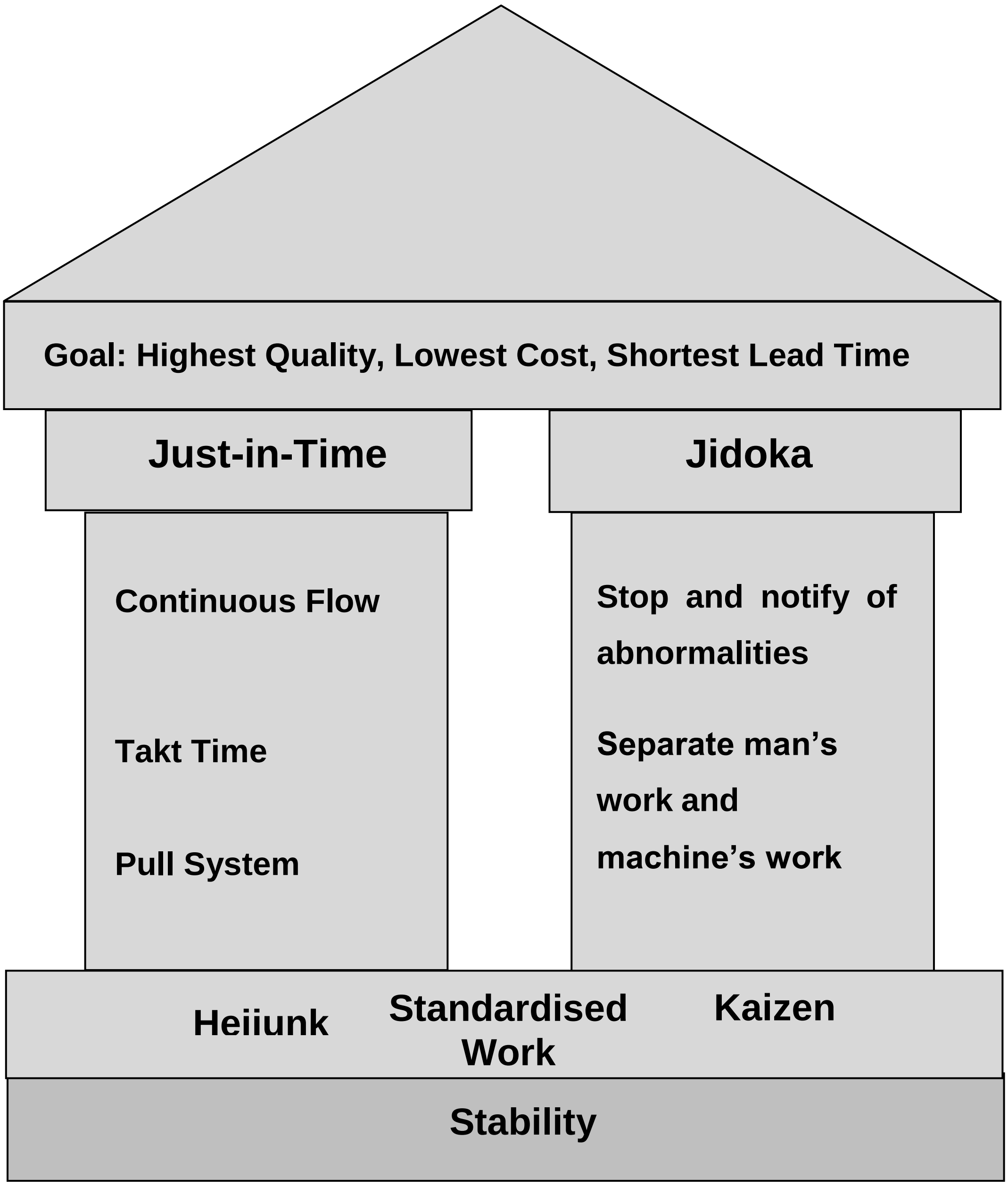


Figure 2.3: Toyota Production System "House" (source: TPS Handbook)

2.4.2 A Review of Lean Measures

The term leanness has often been used in LM to describe the quantitative evaluation of lean production performance. In addition, organisations implementing lean philosophy and systems usually track their implementation progress using lean performance measures (Lawrence and Hotenstein, 1995). While lean take-up has enjoyed a steady growth, however, there is no universally agreed quantitative and synthesised measure for establishing the overall leanness of a firm (Wan, 2006). Early attempt at establishing a measurement for lean production performance was by Karlsson and Ahlstroem (1996), since then other models, methodologies, and tools for assessing the state of leanness of an enterprise have emerged. Most of these models attempt to evaluate a company's leanness or degree of leanness in order to identify operational areas for targeted improvement. For instance, Matawale et al., (2012), using the concept of grey relation theory, developed a quantitative analysis framework to evaluate the overall lean performance measure of an organisation. The leanness index consist of various lean enablers, including management responsibility, manufacturing management leanness, workforce leanness, technology leanness and manufacturing strategy leanness. The model assesses existing lean performance to identify weak performing areas for targeted improvement opportunities.

However, it is also important to stress that lean tools and practices are inexpensive to implement as they do not require investment in any special high-technology capital equipment. Couple with this is the realisation that efficiency gains resulting from the implementation of lean manufacturing techniques can enable companies to achieve more with less. All this has encouraged the take-up of lean practice in many diverse business sectors outside manufacturing, including education, healthcare, financial, IT, construction, process industries and other public/private service sectors (Reijula and Tommelein, 2012). A review of the literature reveals a number of manufacturing practices that are commonly associated with lean production. Table 2.1 summarises leanness measures and their appearance in key references (Hu, 2012; Shah and Ward, 2003). However, limitations persist in measuring company-wide leanness because there is no universally agreed measure, more so, in cases where academics have develop leanness index, the complexity of such measure makes their implementation cumbersome.

Parameters / Lean Indicators	Sugimori et al., 1977	Monden, 1981; Pegels, 1984	Wantuck, 1983	Lee and Ebrahimpour, 1984	Suzaki, 1985	Finch and Cox, 1986	Voss and Robinson, 1987	Hay, 1988	Bicheno, 1989	Chan et al., 1990	Piper and McLachlin, 1990	White, 1993	Shingo Prize Guidelines, 1996	Sakakibara et al., 1997	Koufteros et al., 1998	Flynn et al., 1999	White et al., 1999	Sánchez and Perez, 2001	Rachna Shah, Peter T. Ward 2003	Ray et al., 2006	Wong et al., 2009	Zanjirchi et al., 2010
Bottleneck Removal (Production Smoothing)																						
Cellular Manufacturing										*			*	*	*	*	*					
Competitive Benchmarking																						
Continuous Improvement Programs			*				*	*	*	*		*	*	*	*	*	*	*				
Cross Functional Workforce	*			*		*	*			*		*	*	*	*	*	*					
Customers Involvement																			*		*	*
Cycle Time Reductions										*			*	*		*	*					
Employee Engagement																			*			*
Focused Factory Production										*		*	*	*	*	*	*					
Inventory Turnover																				*	*	

Table 2.1: Lean practices and their appearance in key references (adapted from McLachlin, 1997; Shah and Ward, 2003)

JIT/Continuous Flow Production	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			*
Lot Size Reductions	*	*		*	*	*	*	*	*	*	*	*	*	*		*	*					
Maintenance Optimisation																						
New Process Equipment/Technologies										*			*			*					*	
Planning and Scheduling Strategies																					*	
Preventive Maintenance			*			*		*	*	*	*	*	*	*	*	*	*					
Process Capability Measurements/Control										*			*	*	*	*						*
Pull System/Kanban	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*			*
Quality Management Programs		*																				
Setup Time Reduction / Quick Changeover Techniques	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*			*
Reengineering Production Process																			*			
Safety Improvement Programs										*			*			*					*	
Teamwork /Self Directed Work Teams	*							*	*	*	*	*	*	*	*	*		*				
Suppliers Integration																		*	*		*	*
Total Quality Management	*						*	*	*	*		*	*	*	*	*	*					

Table 2.1 Continued: Lean practices and their appearance in key references (adapted from McLachlin, 1997; Shah and Ward, 2003)

2.4.3 Limitations of Lean Manufacturing Implementation

Due to the outstanding performance of the lean production system, many companies in fields as diverse as aerospace, consumer products, metals processing, auto parts, cell phones, computer, service industry, and industrial products have tried to adopt this production system. Some of the reported benefits of just-in-time or lean production implementation found in the literature include reduced lot sizes, lower inventory, improved quality, reduced waste and rework, improved motivation, greater process yield, increased flexibility, reduced space requirements, lower overhead, reduced manufacturing cost, reduced lead time, elimination of certain trade-offs (e.g. cost vs. quality), improved problem solving capabilities, standardisation of work, continuous process improvement, flexible labour force, elimination of non-value adding time, and production level stabilisation (Schonberger, 1982; Voss and Robinson, 1987; McLachlin, 1997).

However, there are few reported successful cases of Western firms who have managed to emulate Toyota in order to gain global prominence or industry leadership (Dertouzos et al., 1989). Inability of other manufacturers to successfully replicate Toyota’s performance is frequently linked to many root causes such as piecemeal implementation of lean production. Rather than implementing a complete lean production philosophy with the core elements, many Western firms attempted to implement only particular elements of the system, that were easy to implement and provide quick reruns, thus realising limited benefits

(McLachlin and Piper, 1990; Safayeni et al., 1991; Vastag and Whybark, 1993).

Westbrook (1988) and Lieberman (1989) also reported that many Western manufacturers overlooked the human resources policies associated with lean implementation, thus lean implementation in the West tend to be superficial and insubstantial (Shingo, 1988). However, Spear and Bowen (1999) argued that cultural limitation to successful implementation of lean or TPS does not hold because other Japanese companies such as Nissan and Honda have fallen short of Toyota's standards. More so, Toyota has successfully introduced its production system all around the world including North America and Europe where the culture of the workforce and management practices are different from Japan. Spear and Bowen (1999) suggested that the reason for the failure of other manufacturers to effectively imitate Toyota's success lies in observers confusing the tools and practices with the production system itself. While Toyota's operations are seen as flexible and adaptable, however, activities and processes are constantly been innovated and improved to higher level of performance.

Spear and Bowen (1999) positioned that the rigid specification of the production system is what makes it flexible and responsive. Toyota production system uses a problem solving scientific method of experimentation that assess current state of affairs and produces a plan for improvement. As a result, the tactic knowledge and the rules that underline the company's production system are not explicitly written down or consciously designed, but discovered from day to day workings of using a 'learning by doing' approach to problem solving. Whereas, the tools and practices, such as 5s, kaizen, poka-yoke, kanbans, production levelling, preventive maintenance, and rapid machine setup, have been fully described and documented in literatures. More so, these tools and practices, referred to as "countermeasures" and not "solutions" are not fundamental to the Toyota's Production System but seen as "temporary responses to specific problems". Confusing the tools and practices with the production system explains why outsiders find it difficult to grasp and imitate the success of Toyota's Production System.

Other explanations that have been provided for problems in lean implementation in the literature include that Western manufacturers often see only the existing processes rather than the several painstaking steps that have preceded them (Voss and Clutterbuck, 1989). In addition, Western companies often rush to embrace "leanness" forgetting about the complementary issue of "fitness", in particular organisational and industrial contexts. Bicheno, et al., (1997) explained that the concepts of both leanness and fitness have been poorly articulated partly because generalisations are fraught with difficulties, but mainly due to lack of attention paid to the constituent dimensions and their implications for managers.

In summary, implementation of lean production can re-shape operating performance, however, manufacturing firms still need to understand the overarching architecture of the strategy, and adopt coherent approaches that utilises lean tools effectively. Furthermore, the implementation of lean production is not enough to guarantee competitiveness because competitive environment are more turbulent and technological changes in manufacturing techniques are rapid. Therefore, manufacturing strategies cannot be static and must continue to evolve to provide the capabilities that are required to achieve competitive fitness necessary to support and drive the enterprise.

2.5. Agile Production System

In the 1980s Western manufactures were in a transition mode to bring their companies to world class status (Sheridan, 1993). However, by 1990s the nature of the competitive landscape had become truly global, and customer demands of smaller quantities of more customised products were becoming a competitive dimension. The changing nature of the competition implied that the traditional manufacturing organisations pursuit of greater flexibility, elimination of excess in inventory, shortened lead-times, and advanced levels of products quality through lean implementation were not enough. In addition, turbulent times and uncertainty in the business environment have been recognised as the cause of most failure in manufacturing industry (Small and Downey, 1996).

These changes were driven by the twin forces of information technology and globalisation, hence, the use of TQM methods, just-in-time manufacturing techniques like cellular manufacturing, quick change-over, one piece part flow, kanban, and zero inventories, are no longer sufficient to meet the new challenges (Nagel and Dove, 1991; Dove, 1993; Goldman and Nagel, 1993; Sheridan, 1993; Kidd, 1994; Kidd, 1995; Goldman, 1995; Struebing, 1995, Richards, 1996).

While lean practices and tools were seen as highly commendable, many Western manufacturing practitioners, researchers, and managers increasingly agreed that given the rapid rate of changes in the business environment continuous improvement was not enough to meet the demands of tomorrow's standards. In 1991, the concept of agility was formulated by a U.S. congress-industrial-academic forum setup to develop a vision of a successful industrial base for the 21st century. Goranson (1999) argued that agile manufacturing presents the enterprise with a tool to respond to *unexpected change* and then leverage that ability as a competitive strategy. Agile manufacturing (AM) was to enable companies to have much wider product ranges, and to introduce more new products more quickly. The driving forces behind the shift to AM are the use of choice as a dimension of competition, and the proliferation of information technology through 21st century (Oleson, 1998; Yusuf et al., 1999; Sanchez and Nagi, 2001).

2.5.1 Paradigm Shift towards Mass Customisation

The strategic vision of AM is the development of enterprises that can continually reinvent themselves. This involved creating a manufacturing strategy that matches constantly changing market requirements to the factory's capabilities. Figure 2.4 illustrates the development of a coherent AMS. As a strategy, AM is concerned with the development of enterprise-wide capabilities that include structures, processes, technologies, methods, and resources, necessary to thrive and prosper in a changing business environment.

In order to produce customized products at mass production prices and with short lead times, AM requires appropriate supportive production operations systems (Hasan et al., 2012). AM approach enables the manufacturing firm to exploit opportunities inherent within a turbulent environment. An agile company is one that embraces change and adapt to it rapidly and easily. Agility means been able to reconfigure operations, processes, and the business relationships efficiently while at the same time taking advantage of opportunities in an environment of continuous change (Hormozi, 2001). Hasan et al. (2012) affirmed that a robust AM system needs to be able to handle a variable product range and the continuous introduction of new products resulting from customized customer demand.

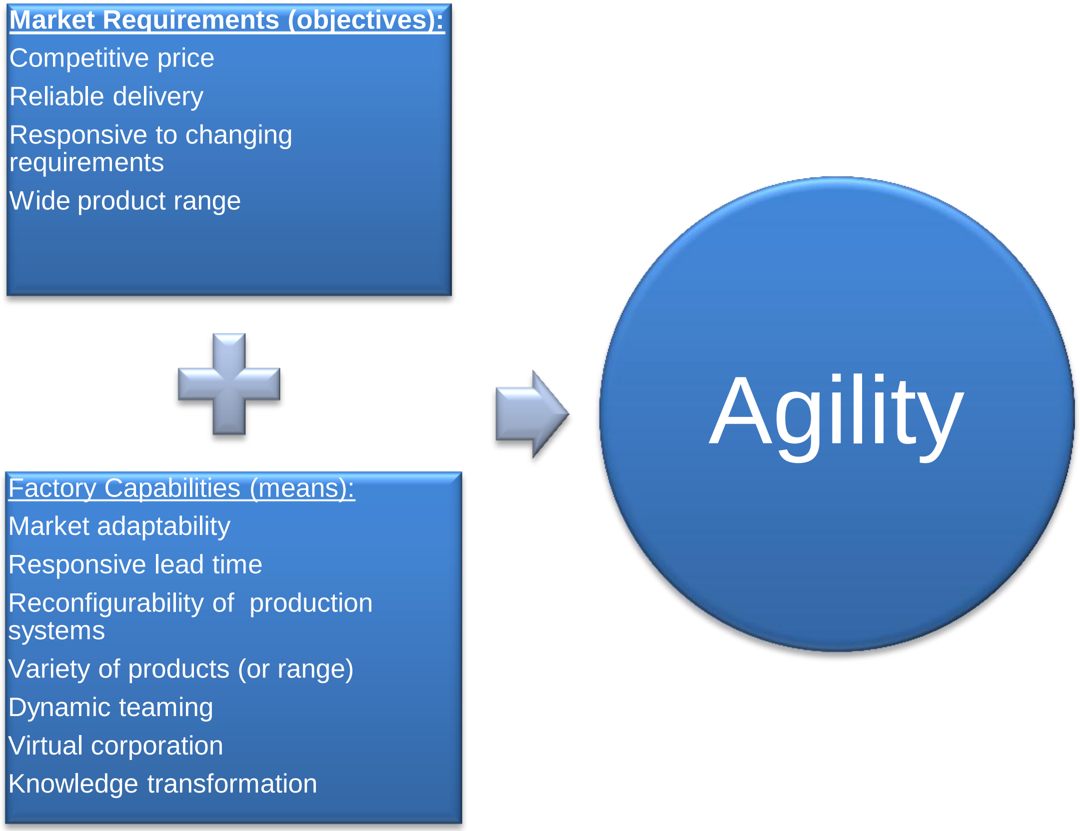


Figure 2.4: Elements of agile manufacturing

Given this backdrop, an agile enterprise was described as one with the following capabilities (Nagel and Dove, 1991; Goldman and Nagel, 1993; Kidd, 1994; Esmail and Saggu, 1996):

- Able to recognise that the nature of competition in the ‘new economy’ is constantly changing and unpredictable
- Ability to quickly out-source and create virtual corporations with other firms that enable synergy gains through resources sharing and collaborative workings
- Utilise nimble enterprise-wide structures of knowledgeable and empowered workforce to deliver time-to-market attribute of competitiveness
- Implement responsive production system that can quickly bring out high quality of mass customised products. These products have very short life-cycles, and very short development and short production lead time are required.
- Drive the production process through the use of reprogrammable, reconfigurable, continuously changeable production system
- Treat customers as individuals and therefore produces to order, rather than to stock and sell – excel at low volume, high variety production

- Produce batch sizes of one at cost comparable with mass production i.e. produce one unit of each of 10,000 different configurations of a single product at the same cost as 10,000 units of one module

- To utilise empowered teams

A shift towards an agile enterprise is to enable the manufacturing enterprise exploit the opportunities in a climate of uncertainty through the implementation of mass customisation (Esmail and Saggu, 1996). The trend toward mass customisation is intensified because customers no longer falls into the easily defined market segments, but rather customers define themselves along the dimension of choice – specific needs and requirements for products and services (Moad, 1995).

Figure 2.5 illustrates a matrix of production systems along the dimensions of ‘response to changes in environment’ and ‘product variety’. The figure highlights that craft production system offers high level of product variety but the production system responsiveness is low. Mass production system is depicted as having low product variety and low system responsiveness. On the other hand, lean production system is shown as a production system that offer low product variety but high system responsiveness, whereas, the agile production system through its customisation capability offer high product variety and high level of response to changes in the market place.

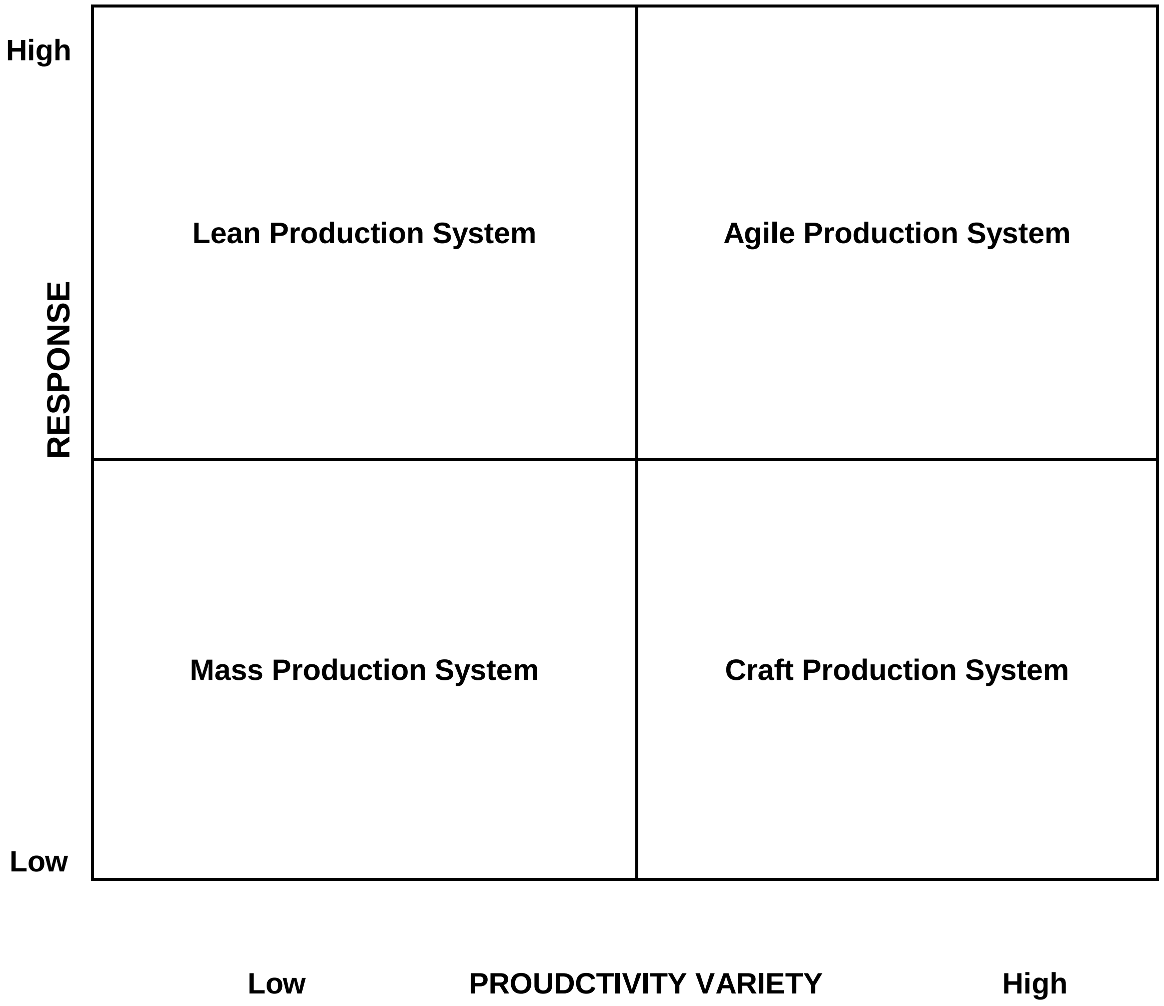


Figure 2.5: A matrix of production system performance against product variety and responsiveness (adapted from Esmail and Saggu, 1996)

2.5.2 Lean vs. Agile Manufacturing

Sometimes, the two terms, lean and agile manufacturing, are confused as if they are synonymous. Some of this confusion (James, 2005) occurs with agility being used to describe changes and ideas being promoted as lean production such as business process re-engineering, time compression, extended (or virtual) enterprises, and so on (Kidd, 1994; 1995, Dove, et al., 1996), Though the two concepts overlaps because AM is seen as an enhancement of lean production in that AM has the capability of producing much more highly customised products, serving smaller niche markets of increased scope, much faster and more cost effectively (Li et al., 2003).

Furthermore, Li et al., (2003), claimed that lean production is generally only associated with the efficiency of the factory floor, whereas AM requires an encompassing strategic view and embodies concepts such as rapid alliance formation and virtual enterprises in order to introduce new products very quickly and efficiently. In addition, some of agile approaches and practices such as concurrent engineering, empowerment, learning organisation and so on already exist as LM practices (Gould, 1997).

However, the two manufacturing paradigms are different, more so, the proponent of AM argued that the concept challenges lean production and leads to the modification or even abandonment of lean concepts (Kidd, 1994; 1995). LM was described as a collection of operational techniques focused on productive use of limited resources; while the aim of AM is to speed up the process of creating a virtual corporation by speeding up the process of forming partnerships (Kidd, 1994). Table 2.2 represents an attempt to differentiate these two manufacturing paradigms.

Table 2.2 highlights that LM aims to deliver competitiveness at the things the firm can control. This is because lean aims for ‘predictability’ by removing excess resources in cycle time, inventory level, rejection rate (quality standards), manpower utilisation, capacity utilisation, etc. It has been argued that lean is best suited for repetitive volume manufacturer. On the other hand, AM is an overall strategy focused on thriving in an unpredictable environment. The production system is more suitable for dealing with an unpredictable marketplace. To cope with sources of variability, external or internal, agility aims for ‘responsiveness’ actions such as lead time reduction (delivery time), production system flexibility (product range), virtual corporations, team working effectiveness (knowledgeable team), etc. Agility was defined as the ability to thrive and proposer in an environment of constant and unpredictable change (Suri, 1998).

SN	Strategic Objectives		Lean Manufacturing	Agile Manufacturing
1	Dimensions of Competitiveness			
		Quality	*	*
		Cost	*	*
		Delivery (time based competitiveness)	*	*
		Choice (product mix)	Low Variety	High Variety
		Customer value focus	Products	Solutions
2	Competitive Priorities			
		Waste elimination (make information and product flow; pulled by customer needs)	*	▨
		Speed of response to new market opportunities	▨	*
3	Production System Objective			
		Predictability	*	▨
		Responsiveness to changing volumes and product mix	▨	*
		Adaptability	Continuous Improvement	Continuous Adaptation
		Flexibility (flexible technologies and structures required to adapt quickly to changing market requirements beyond product mix and volume)	▨	*
		Production Strategy	Pull System (Kanban)	Pull System
4	Economic Environment	Market focus	Repetitive Volume Manufacturer	Un-predictable Demand Profiles Manufacturer
5	Relationships	People	*	*
		Teams Empowerment	*	*
		Organisation	*	*
		Technology	*	*
		Virtual Partnerships	▨	*

Table 2.2: Lean vs. Agile Manufacturing

In the same breadth, an agile manufacturing system (AMS) has been contrasted to flexible manufacturing system (FMS) according to the type of adaptation. FMS was presented as reactive adaptation and AMS as proactive adaptation (Sanchez and Nagi, 2001). Dove (1996) argued that flexibility is a characteristic that is fixed at specification time. It is a planned response to anticipated contingencies. On the other hand, agility is the ability to deconstruct and reconfigure a system, as needed, to provide a balanced response-to-change capability across the four dimensions of cost, time, robustness, and scope; with scope being the principal difference between flexibility and agility (Jackson and Johansson, 2003).

Furthermore, there exist some ambiguity in the literature in the tools and practices referred to as AM (James, 2005); more so, there are various implemented ideas and models being promoted as agility.

2.5.3 Measures of Agile Manufacturing

There are a number of agility performance models in the literature, and these methods for measuring AM varied from focus on a measure of agility through assessment of organisational structure of a company (Vinodh et al., 2009); to product development (Seiger et al., 2000). Yauch (2011) also pointed out that the wide array of measurement approaches focus on different operational/structural characteristics of organisations with some approaches assessing agility from the view point of particular processes, whole supply chains, or individual business units. Perhaps the varied approaches to measuring agility reflect the evolving nature of the concept which is frequently presented as an integration of technologies, people, facilities, information systems, and business process (Shih and Lin 2002).

Tsourveloudis and Valavanis (2001) argued that agility metrics are difficult to define due mainly to the multidimensionality and vagueness of the concept. The authors proposed a knowledge-based framework as a model for evaluating an enterprise overall manufacturing agility. The framework, represented via fuzzy logic model, makes use of a set of quantitatively defined agility parameters grouped into production, market, people and information infrastructure. Yauch (2011) also developed a quantitative model for assessing agility as a performance outcome based on four combinations of organisational success and environmental turbulence.

Kurian (2006) also pointed out that there is no standard method for measuring agility and expert guidance is not readily available. The author asserted that a quantitative definition of agility is desirable in order to measure the degree to which an entity is agile. Beck (2012) also asserted that a formal method to incorporate the many components of the agile manufacturing is yet to be developed. However, some other authors consider the supply chain to be the critical measure of AM (Kumar and Motwani, 1995). However, regardless of what method of agility measurement is adopted, Harvey (2012) pointed out that certain methods fall short in a number of ways:

- Often some of the measures of agility do not result in a single numerical value that can be utilised for further research or statistical analysis
- Some measures are too narrow or too broad since they were developed for specific types of industry, hence, such models cannot be relied on to use to make comparisons.
- Use of qualitative and fuzzy logic models, as opposed to quantitative ones, often lead to increased complexity in application and are opened to subjective ratings and opinions which can affect the reliability of results.

In summary, Table 2.3 summarises the evolution of mass customisation as a competitive strategy and highlights key underlining developments in manufacturing practices and focus.

Phases of Evolution of Manufacturing Strategies	Awareness Period	Production Philosophy	Underlining Tools, Practices & Concepts
Ford Motors: the universal car concept	Mid 1920s	Mass Production	Introduction of conveyor-driven flow production Use of standardised interchangeable components Use of inventories to buffer production process Machine automation line assembly Organisation of work in a logical sequence
General Motors: the concept of a car for every purse and purpose	Mid 1950s	Flexible Production	Annual model roll out through the concept of planned obsolescence Broad product line Diversified mass marketing Automotive design (styling)
Toyota Motors: the concept of compact cars with better value	Mid 1970s	Lean Production	The principle of Jindoka, which means the machine stops itself when a problem occurs Just-in-time concept with the underlining pull-system and use of kanban (signals) ensure continuous flow of producing only what is needed Team empowerment and involvement Standardisation of products and processes Continuous improvement which refers to the continuous reduction of cost by identifying and reducing waste and non-value added activities
American Manufacturers: the concept of highly individualised, high differentiated product	Mid 1990s	Agile Production	The hybrid production system that combines Japanese production model and US-American management method of work orientation(“job thinking”) Integration of traditional production model of high scope production, with lean philosophy of high quality, and new radical elements such as high product customisation The concept of virtual relationship and project management using lean and flexible project teams High product customisation with high innovation, and high production flexibility with many product variant and optimum process responsiveness

Table 2.3: Evolution of Mass Customisation as a Competitive Strategy

2.5.4 Limitations of Agile Manufacturing Implementation

The implementation of agility is still very much a frontier activity, involving radically new concepts concerning strategies, organisation, people and technologies (Dove, et al., 1996). Agile implementation requires much effort and changes. Indeed the requirements for successful implementation of agile manufacturing in some industries are far reaching. This may requires changes in communication infrastructure, education and training, trading and legal issues, as well as government regulations in terms of environment and labour times to make enterprise more flexible, responsive and efficient in continuous adaptation. In addition, implementation of AM in companies requires companies to change how they design, manufacture, and market their products (Gross, 1992).

In addition to the structural requirements for AM implementation, there also exist a range of confusing views on the criteria for attaining agility. Some authors such as Crocitto and Youssef (2003) advocate a focus on people with leadership as the key to agile manufacturing, other researchers (Sieger et al., 2000; Hoek et al., 2001) emphasize the importance of supply chains when striving for agility. On the other hand, some other authors like Zhang and Sharifi, (2000) emphasis focus on the management aspects of the organisation or towards the manufacturing strategies. Vokurka and Fliedner (1998) outline strategies towards agility with the following initiatives:

- Reductions in manufacturing cycle times and order response times
- Partnerships
- Outsourcing
- Schedule sharing
- Supply chain performance improvements
- Postponement
- Teamwork and cross-functional management teams
- Employee education, training and empowerment
- Business process re-engineering

The implementation of AM calls for the development of company-wide strategic vision and the understanding that agility is a long-term issue for businesses, and not a short-term operational objective. Kidd (1996) argued that agility is a paradigm shift and its implementation requires a major change exercise of accepting that current practices and beliefs are no longer appropriate or relevant.

Employees also need to be willing to expand their horizons in order to achieve greater creativity and flexibility in the way they perform their jobs. Indeed, agile implementation requires a highly motivated workforce. Under agile manufacturing system, the emphasis is on producing highly differentiated products with shorter life span.

2.6. Economic Sustainability: A Dimension of Fit Production System

Within the context of FM, economic sustainability is defined as the ability of a firm to be efficient and capable of not only short-term growth but also long term viability. The term sustainability can be applied to a variety of concepts and is often taken out of context (Pham et al., 2007, 2011). For many people sustainability translates to looking after the environment by waste management, protecting wildlife, recycling and using renewable sources of energy. To others, the concept of sustainability is seen as a combination of environmental, social and economic performance, as illustrated in figure 2.6 (Dyllick and Hockerts, 2002).

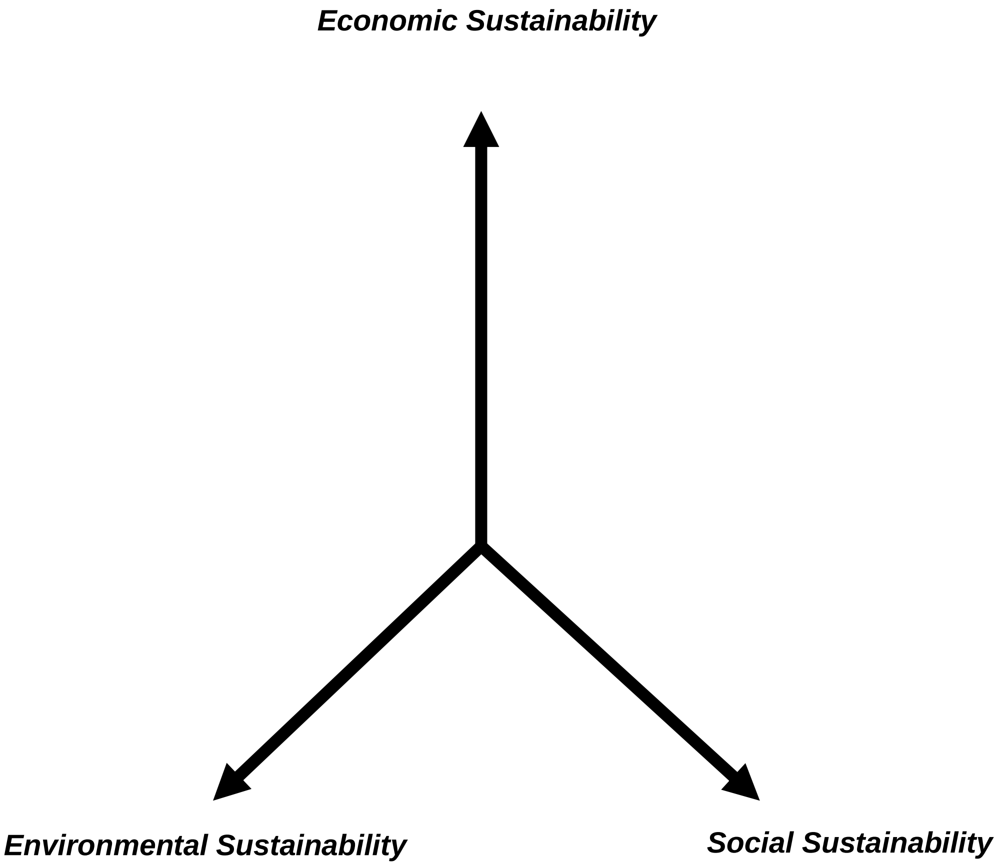


Figure 2.6: Triple bottom line of corporate sustainability
(After Dyllick and Hockerts (2002)

2.6.1 Dimensions of Economic Sustainability

While interest in the concept of environmental sustainability appears to be well understood within business circles, the ideas behind economic sustainability appear elusive (Doane and MacGillivray, 2001; Found and Rich, 2006; Pham et al., 2007). Some authors have suggested that economic sustainability could be viewed as a process or an end-state (Pasmore, 1988; Hines et al., 2006). It is possible to argue on either side of the issue due to the paucity of clear-cut evidence or well researched theories on economic sustainability. However, once the nature of the concepts is made clear to businesses, most would desire to be sustainable to prevent corporate premature death and the resultant job losses (Doane and MacGillivray, 2001). Moreover, manufacturing firms are witnessing increasing pressures from customers, competitors, shareholders, lenders and legislators. These pressures are exacerbated by the forces of globalisation, trade liberalisation and rapid technological changes. Survival for companies has never been so difficult to guarantee as at present (Huyett and Viguerie, 2005).

With FM, the driving idea is to encourage business managers to formulate and pursue not only short-term efficiency and profitability goals but also long-term survival goals such as investment in the right capabilities and the acquisition of survival skills. Kaplan and Norton (1996) argued that for a company to grow and prosper there must be more of a ‘fit’ view taken of its operations rather than simply to concentrate on its manufacturing operations or financial capabilities. The danger of focusing on meeting short-term operational goals is that management can be lulled into a false sense of security by taking present operating conditions for granted. They would make no preparation for changes in the business environment and when crises develop without warning, such as the down-turn in the global economy of 2008/2009, they are caught ‘napping’ and thus fall easy victims.

The need for a company to take a more holistic view of the wider business issues surrounding sustainability is therefore critical. FM strategy integrates the broader perspective of how to manage long-term economic performance with business capabilities development, knowledge management, stakeholder involvement and corporate governance. Under the broader perspective, four types of metrics of economic sustainability for manufacturing firms are presented (see figure 7). These metrics reflect the five major dynamics that are shaping global manufacturing – technology exploitation, investment in intangibles (such as intellectual property, brands and R&D), prevalence of global value chains and specialisation, people and skills and a low carbon economy (BERR, 2008) – and the four major business perspectives for sustainable growth – financial, customer, learning and growth and internal business (Kaplan and Norton, 1996). The fitness metrics provide a broader means for manufacturing firms to evaluate how short-term operations help the firm to achieve sustainable success and continuous survival. This approach also incorporates the need to excel in the six indicators of sustainable manufacturing, namely (Pham et al., 2007): people, product, process, partnership, place and profit.

Leanness and agility focus on enhancing the current performance of a manufacturing organisation rather than on planning for the company's future. Conversely, economic sustainability aims to maintain competitiveness in a holistic manner, which is essential to enterprise longevity in a rapidly changing market. Figure 2.7 illustrates the dimensions of economic sustainability within the context of fit manufacturing.

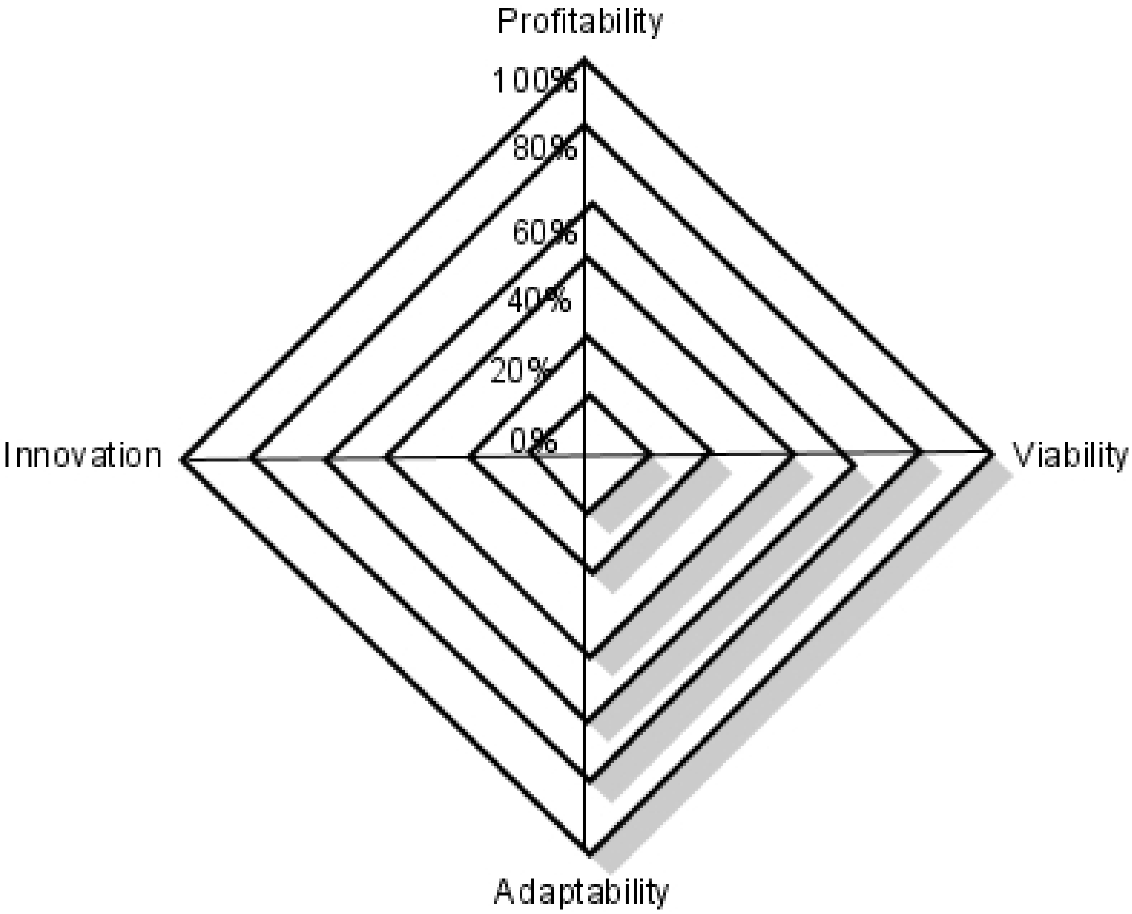


Figure 2.7: Dimensions of economic sustainability

2.7. Motivation for Fit Production System

Michael Porter (1980) in his work on competitive strategy identified three generic strategies that are commonly used by businesses to achieve and maintain competitive advantage. These generic strategies are defined as cost leadership, differentiation, and focus. Several researchers have questioned Porter's generic strategies model and it use (Datta, 2009; Ghoshal and Bartlett, 1989; Hamel and Prahalad, 1994). A major criticism of the framework is that it is 'static' and its application limited to stable market condition. The model also failed to recognise that differentiation and cost leadership can coexist within a market player without requiring a different culture or totally different philosophy. Datta (2009) suggested that differentiation strategy offer superiority over cost leadership in sustaining competitive advantage, and cost leadership strategy is "internally, rather than externally, or customer-oriented".

On the other hand, some authors are of the view that manufacturing companies compete primarily on the priorities of customer satisfaction; defined by quality, responsiveness, flexibility, and value (Purdum, 2003; Chikan and Gelei, 2010). Wagner et al., (2012) also positioned that firms with higher financial performance measured as Return on Assets (ROA) exhibit strong relationship in supply chain fit i.e. "strategic consistencies between the product's supply and demand uncertainty and the underlying supply chain design".

Two different models describe the relationship between competitive priorities; these are the traditional trade-off model, and the cumulative model (Boyer and Lewis, 2002). Proponents of the traditional trade-off model such as Skinner (1969), Hayes and Wheelwright (1984) argued that manufacturing plants should focus on one priority at a time, because cost, flexibility, quality, and delivery capabilities require different operational structures and infrastructure for support. According to Hayes and Wheelwright (1984), the choice of competitive priorities can be reduced to between seeking high profit margins and high output volumes. Hayes and Wheelwright (1984) were of the view that for safety and practical purpose, it is both difficult and dangerous for a company to try and compete on all the dimensions of price, quality, dependability, and flexibility simultaneously.

On the other hand, proponents of the cumulative model such as Boyer and Pagell (2000), Corbett and Van Wassenhove (1993), asserted that global competition has intensified the pressure on companies to improve along all competitive dimensions, and manufacturing companies can compete on multiple competitive priorities simultaneously because of the developments in Advance Manufacturing Technologies and Information Technology. Although the trade-off model and the cumulative model appears to emphasis different approaches to competitive priorities, Schmenner and Schwink (1998) point that the law of trade-offs is reflected in comparisons across plants at a given point in time, whereas the law of cumulative capabilities is reflected in improvements within plants over time.

However, for the purpose of the development of FM, it is argued that the most valuable asset that a manufacturing company has is customer intimacy, customer knowledge, customer connections and proximity to them. This valuable asset gives a manufacturing company ability to customise its products to customer satisfaction. Consequently, meeting and exceeding customer's expectations in terms of cost, quality, value, and speed is taken as primary in today's fierce competitive environment. This competitive requirement continues to force many manufacturing companies to focus on achieving greater efficiency and effectiveness at little or no additional cost. This demands superior level of competitive fitness and the ability to integrate competitive capabilities with the goal of economic sustainability. It is evident therefore, that integration is crucial to a firm's ability to rediscover superior manufacturing capabilities and deliver sustainable competitiveness.

2.7.1. Integration as a Strategy for Fit Production System

In the field of systems engineering, integration is commonly described as a strategy for bringing together components subsystems to form one system and ensure that the subsystems function together as a whole. Applying the concept of integration as a competitive manufacturing strategy aims to extend the traditional approach of matching manufacturing structure and infrastructure with business strategy through a formal planning process (Skinner, 1969). Hayes and Pisano (2000) argued that given today's turbulent competitive environment, integrating manufacturing strategy with the concepts of core competences and learning organisations enables the organisation to achieve world class performance. Lee (2002) suggested that firms should integrate manufacturing functions and business strategy all together into an information system. Various methods of integration are highlighted in Table 2.4 (Gold-Bernstein and Ruh, 2004).

Hsu and Rattner (1993), defines integration as "the degree to which productivity approaches a theoretical upper bound". Hsu (2012) further suggested that integration may lead to transformation and new service business designs. On the other hand, Merriman (1996) argued that system integration is about "gluing" together all the components that enables a system to deliver its over-arching functionality. This requires designing an integrated system by adopting a holistic view. True integration requires that control over a system's subcomponents is achieved to ensure the synergistic contribution of the subcomponents (Mejabi, 1994) that the constituent elements can work together to produce the desired result. This involves identifying the *relationships* between all components subsystems (elements), including communication channels, communication protocols, *interfaces* and other connections between them; identifying the different *operating conditions*

Vertical Integration	**Star Integration (a.k.a. Spaghetti Integration)**	**Horizontal Integration**
Objectives: Integrate subsystems according to their functionality by creating entities referred to as 'silos'.	**Objectives:** Integrate subsystems whereby each subsystem is interconnected to each of the remaining subsystem. The connections, when observed, looks like a start but when the overall system is presented, the connections look like spaghetti.	**Objectives:** Here, the process of integration requires reducing the number of connection interfaces to only one per subsystem through a dedicated specialised subsystem that communicate with other subsystems.
Advantages: Integration is performed quickly, and the integration method is cheaper in the short time	**Advantages:** This method yields integrated system that has extreme flexibility functionality. Re-usability of subsystems to create additional functionality is allowed	**Advantages:** This method yields integrated system that has extreme flexibility functionality that allows for the replacement of one subsystem with another subsystem that provide similar functionality
Disadvantages: Reusing subsystems to create another functionality is not allowed	**Disadvantages:** The time and cost of integration can be substantial depending on the complexity level of subsystems connectivity required	**Disadvantages:** The horizontal integration scheme can be misleading and The time and cost of integration can be substantial depending

Table 2.4: Methods of integration

that the system will function under – normal state and transient – and the *disturbances* that it might be subjected to (Pham and Pham, 2008).

In manufacturing systems, two type of integration are possible - fixed integration and flexible integration. Under fixed integration the combinations of subsystems making a larger system is fixed and cannot be modified. On the other hand, a loose combination of subsystems is defined as flexible integration. Under flexible integration, the configuration of the larger system is easily modified in response to changing requirements (Mejabi, 1994). Subsequently, a fit manufacturing (FM) is proposed as a bottom-up flexible integration of subcomponents – lean, agile, and economic sustainability. Fit manufacturing strategy aims to combine the strengths of leanness and agility with sustainability to deliver long-term fitness. Economic sustainability (ES) is introduced as a subcomponent of FM to enhance sustainability of the enterprise competitiveness.

Integration of LM and AM with economic sustainability is necessary because LM and AM strategies are structured to help manufacturing companies to face increasingly intense competition by improving their productivity. Although, continuous productivity improvement is a key requirement for a long-term future, is not, on its own a sufficient condition for sustainability. For instance, lean production in its purest form focuses on how to use a pull system (kanban) to respond to customer requirements (Bunce, 2003). While such a system might be efficient at manufacturing products wanted by the market, it cannot anticipate changes in customer requirements or the need to adjust product offerings to, or ahead of, those changes.

More so, the failure of lean and agile manufacturing paradigms to help organisations achieve long term economic sustainability (Hines et al., 2006) calls for a shift in focus from achieving short term competitive advantage through operational cost reduction, product flexibility and responsiveness to a “total” manufacturing initiative that is pro-active to market changes and has the ability to integrate the manufacturing efficiencies achieved through lean and agile with sustainability. The new manufacturing paradigm, called fit, has a number of advantages over the traditional thinking that view lean and agility as two distinct manufacturing techniques. Therefore, the integration of lean, agile with sustainability provides a more holistic and prolific approach for both academic studies as well as helping practitioners to achieve economic sustainability with limited disruption to their current manufacturing initiative. In addition fit assess, analyses and strengthen the core components of a manufacturing firm with a long term economic sustainability viewpoint to ensure that the company’s economic growth is not competitive now but also sustainable as markets change in the future.

Figure 2.8 illustrates the bottom-up integration approach of fit manufacturing (FM). In the graphical illustration, lower level subsystems – lean and agile manufacturing – are grouped into advanced manufacturing technique. The purpose of grouping lean and agile manufacturing techniques into advance manufacturing strategy is to produce a fit system that removes the overlap that exist between these two paradigms, and focus on defining key parameters indicators for measurement and increase the probability of success, including ensuring the overall system displays the required functionality.

The integrated structure of FM is predicated on the ability to achieve trade-offs between the subcomponents while ensuring each subsystem functionality is maintained. The above argument, coupled with the need to breakdown the manufacturing system into parts and improve efficiency of the whole by improving efficiency of each part, is central to the theme of integration and implicitly to the FM concept.

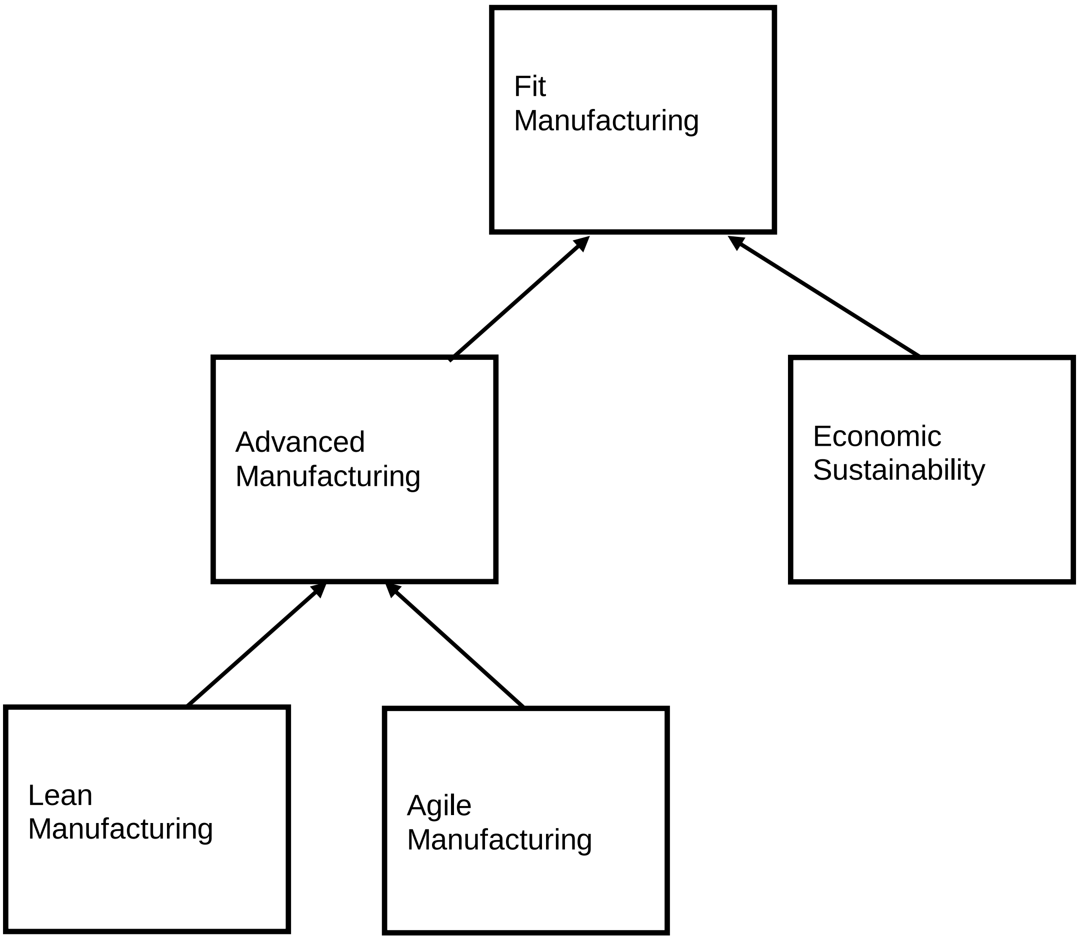


Figure 2.8: Bottom-up integration approach of fit manufacturing modelling

2.8 Summary

This chapter has reviewed the evolution of production systems. The evolution of manufacturing strategies from mass production, flexible production, lean production, agile production, to integrated manufacturing was presented. Lean and agility manufacturing paradigms were presented as being applied in many industrial sectors today. Lean was discussed as a strategy for achieving continuous improvement in business performance through identifying a company's value stream and then systematically removing all waste. On the other hand, agility was presented as a manufacturing strategy aimed at achieving manufacturing flexibility and responsiveness to changing business needs.

The inherent limitations of lean and agile manufacturing strategies makes it imperative for the development of a holistic manufacturing model that can be utilised to managed both the short-term goals of production efficiency and the long-term goal of enterprise sustainability. Against this background, the concept of fit manufacturing was introduced as an integrated holistic manufacturing strategy. Combining the efficiencies gains of lean and agile manufacturing with the principles and practices of economic sustainability strengthens re-enforces the need for fit production system (FPS) to meet the concurrent objectives of quality, cost, speed, responsiveness, flexibility, and sustainability. This combination enables a manufacturing firm to improve its competitiveness, its efficiency and performance over long time.

CHAPTER 3

THEORETICAL FRAMEWORK FOR FIT PRODUCTION SYSTEM

Indeed, manufacturing strategy is no longer about making things…"it is about creating operating capabilities a company needs for the future". Hayes and Pisano (2000)

3.1. Introduction

In the preceding chapter, it was argued that the need for a total manufacturing strategy is intensified by the trend in mass customisation which requires companies to provide customised products and services at mass production prices. Fit manufacturing was proposed as a total manufacturing philosophy founded on the theme of integration, by linking the manufacturing efficiencies achieved through lean and agile manufacturing with the overall business strategy of sustainability.

In this section, a theoretical framework for fit production system (FPS) is discussed starting with an attempt to provide an operational definition for the concept to describing the structural and operational characteristics of the production philosophy. Subsequently, attempt is made to expound the central theme of fit manufacturing as a manufacturing strategy essential to creating an integrated view of the factory. The idea of a fitness index is presented and justified. This also lays the groundwork for subsequent evaluation of the individual three fitness indexes, and their combination. The fit production system proposed here is to be tuned along the lines of leanness, agility and sustainability.

3.2. A New World's Economy: New Challenges

The take-up of lean and agile manufacturing by Western companies has not really negated the economic argument to move jobs to low wage economies such as China and India. Neither has it halted the daily reported demise of manufacturing firms which have tried to improve their productivity and competitiveness using these approaches. The competitive advantage gained from the isolated implementation of these paradigms is significantly reduced when the market dynamics change and the struggle for survival takes over (Pham et al., 2011). Although lean and agile initiatives have been known to deliver short-term benefits, implementers of such initiatives have foundered once new challenges emerge. Of the many firms that have tried to implement a lean strategy, only few succeed (James, 2006). For instance, the implementation of lean and agile manufacturing has not shielded Japanese, European and US automobile manufacturers from the global economic downturn of 2008–2009. The financial crisis plunged the car manufacturing industry into near collapse, with two of the US automakers, General Motors (GM) and Chrysler filing for bankruptcy in 2009. In December 2008, Toyota, the originator of lean manufacturing and the world's largest automaker also announced its first-ever projected operating losses in 71 years for the fiscal year ending March 2009 (Kageyama, 2008).

In the UK, despite a reported greater take-up of lean manufacturing by many companies (EEF, 2001), the manufacturing sector continues to witness a steady decline. Perhaps this is because lean and agile manufacturing are fundamentally restrictive in scope. These strategies are structured to help manufacturing companies to face increasingly intense competition by improving their productivity which, although a requirement for a long-term future, is not, on its own a sufficient condition for sustainability. For instance, lean production in its purest form focuses on how to use a pull system (kanban) to respond to customer requirements (Bunce, 2003). While such a system might be efficient at manufacturing products wanted by the market, it cannot anticipate changes in customer requirements or the need to adjust product offerings to, or ahead of, those changes.

The current global downturn calls for manufacturing companies to rethink not only their manufacturing models but also marketing and supply chain strategies as cheap credit becomes unavailable and stricter regulations are imposed on how credit is provided to businesses and individuals. This emerging trend portrays a future where automakers and other manufacturers that rely on large consumer spending might have to plan for a situation where only people with good credit histories that can truly afford new expensive consumer goods will buy them. Otherwise, government would have to provide subsidies as currently being witnessed across Europe, North America and parts of Asia in the form of government-sponsored car scrappage schemes. The implication of this is that sales of new consumer goods, especially those that have tended to be purchased on credit, might be lower than previously experienced. This effectively means that manufacturing companies will have to go beyond cost-cutting strategies and adopt a holistic manufacturing model.

A holistic new manufacturing model must also offer the diverse groups of stakeholders a better guarantee of sustainable prosperity rather than in the past, when stock-market returns were used as the primary measurement of management performance and the well-being of the firm (Lohr, 2009). Accordingly, as the current global downturn runs its course and the struggle for survival reshapes how firms organise and manage their activities, manufacturing companies should look at becoming ‘fit’ and go beyond the achievement of the company’s goals of quality, reduced operational costs and reduced time to market. In the ‘new world’ economy that is likely to emerge from this current global crisis, the attainment of leanness and agility goals for any company is considered a basic requirement in order for the company to survive. Hence, managers of firms must rethink their strategies of being lean or agile and work towards becoming ‘lean, agile, and fit’.

Fit manufacturing (or ‘fit’) requires doing away with the mentality of incrementalism as the means to attain long-term success. Instead, it focuses on building economic sustainability as the goal of a successful enterprise. For the purposes of this work, a description of fit manufacturing in terms of its significance, aims and objectives is provided against the context of other work that touched on the concept of 'fitness'. Key differentiating criteria between fit and other manufacturing initiatives are discussed and the rationale for fit manufacturing is presented. Also discussed are the key components of a fit production system (FPS) and how they are integrated. The chapter also highlights the importance of economic sustainability and how the concept can be further developed in relation to fit manufacturing.

3.3. What is Fit Manufacturing?

The term 'fit' has many broad meanings, including 'fit for purpose' (meeting a qualifying standard); 'fit to be entrusted with a responsibility' (satisfying a condition by character); 'fit as in fitting something' (conforming to some shape); and 'fit as in a fit person' (healthy). In the context of this work, staying fit implies manufacturing firms must develop the ability not only to be competitive, but also to be adaptable, resilient and sustainable for the long term. Manufacturing companies should look at becoming 'fit' through the integration of short-term operational goals with long-term economic survivability. Fit manufacturing therefore provides a model that enables firms to work towards the elusive goal of 'staying healthy' (fit) over a sustained period. The initiative provides a framework by which manufacturing firms can allocate resources, strike a balance among the different types of manufacturing initiatives, respond to disruptive forces, develop appropriate metrics to assess and reinforce the overall long-term fitness of the organisation. Figure 3.1 illustrates a contemporary view of manufacturing strategies with fit manufacturing being the latest initiative.

A fit enterprise is lean, agile and sustainable, and can compete through the creation of value that meet or exceed customer expectations. A fit enterprise is also capable of responding to improvement changes – either to fix a problem or to raise the fitness level - and adapt to environmental changes without jeopardising its overall health. Pham et al. (2011) defines a fit system as “one which, when subjected to a step change or continuous change induced internally or externally by a combination of transformational, transitional and turmoil forces is able to cope with the change and adjust itself overtime without suffering a sustained decline which could lead to total failure”. The preceding definition of fitness encompasses the various scenarios under which a manufacturing system can be evaluated, assed or considered healthy. Consequently, it is important to stress that fit manufacturing is neither an improvement methodology nor a cure-all strategy (solution) for whipping an organisation into shape. Rather, fit manufacturing is about building an unending quest for getting the business fit and keeping fit.

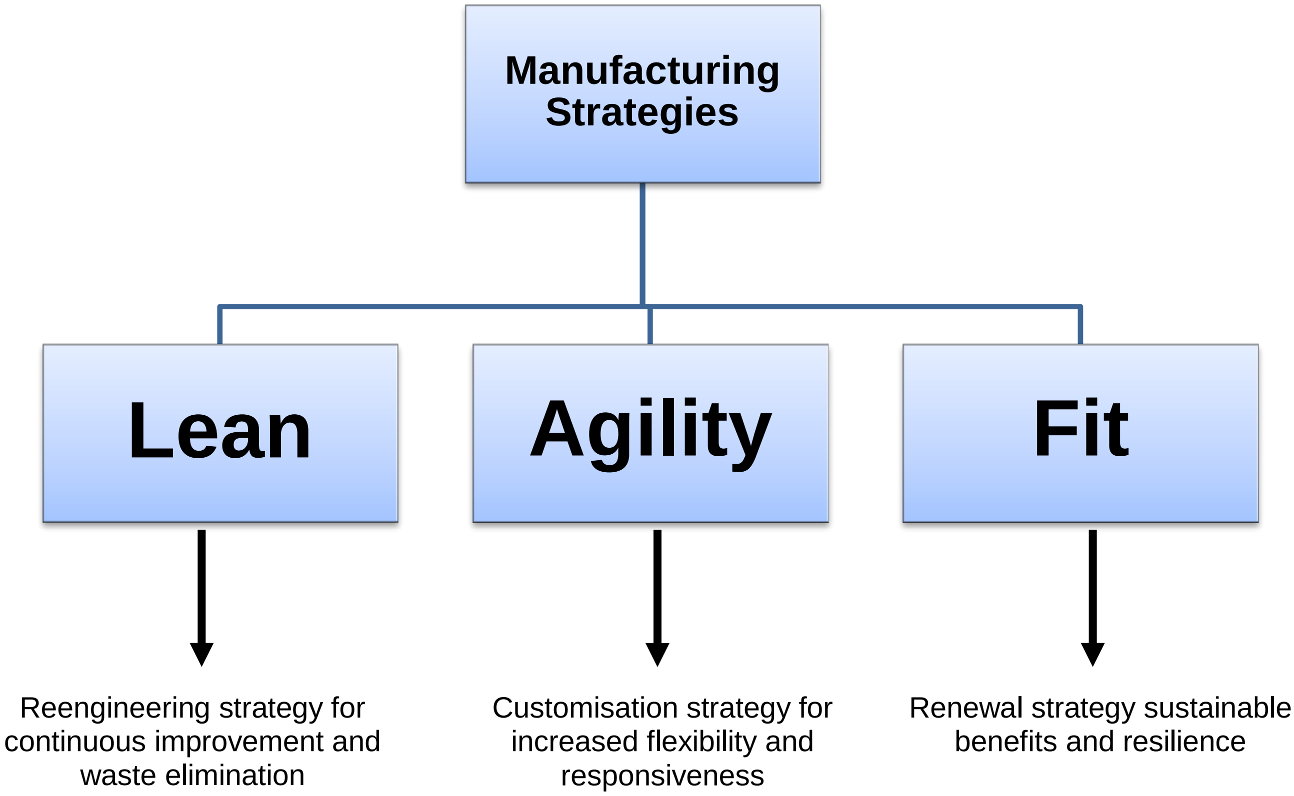


Figure 3.1: A contemporary view of manufacturing strategies

3.4. Fitness in Nature

Elements of fitness can be found in nature through the evolution of increasingly complex organisms. For instance, coyotes (*Canis latrans*) are members of the dog family and found in North America. Unlike its larger cousin the grey wolf which suffered decline from hunting and human encroachment into their natural habitats, the coyote has adapted well and dramatically extended its range, by improving its learning, hunting and dietary adaptability. In areas where wolves are extinct, coyotes have been known to flourish. The animal, which was once a diurnal mammal but has adapted to more nocturnal behaviour (McClennen et al., 2001), can shift its hunting techniques in accordance with its prey. For example, when working as a team, the animal has been reported to kill larger animals like elks and deers and can enter into a symbiotic relationship with American badgers for effective hunting of rodents. Coyotes also start breeding at younger ages and produce large litters to cater for high juvenile mortality rates. The animal is also known for its ability to grow faster than the grey wolf and its lack of timidity towards humans, making it appear better suited to living among people than the wolf (MDNR, 2009). Coyotes are known for their inventiveness, adaptability and good survival skills. These features of coyotes are important characteristics of fit manufacturing which this generation of manufacturing firms should strive to emulate not only to compete now but to survive and thrive well into the future.

3.5 Fundamentals of Fit Manufacturing

Fit manufacturing was first proposed by Pham and Thomas (2005, 2006). The manufacturing concept is described as a total manufacturing philosophy for an integrated approach to the use of leanness, agility and economic sustainability to achieve a level of fitness that is unique to a company. Fit manufacturing was described as a manufacturing strategy which not only develops a company's latent potential to meet new market requirements but also encourages manufacturing firms actively to seek new markets through the use of an advance warning mechanism (AWM). Pham et al. (2008) further asserted that fit manufacturing is largely founded on the theme of integration, by linking the manufacturing efficiencies achieved through lean and agile manufacturing with integrated marketing and product innovation strategies to achieve long-term economic sustainability. Lean was seen as a manufacturing strategy for promoting efficiencies through the elimination of waste, while agile manufacturing was described as a manufacturing strategy that enhances the ability of a manufacturing system to deal with change and uncertainty by building in measures that increase its reconfigurability and responsiveness (see Table 3.1). However, these two paradigms, like other manufacturing strategies purported to provide a 'total' answer to manufacturing problems, did not connect all the elements of a manufacturing organisation in order for the organisation to grow and prosper.

	Craft	**Mass**	**Lean**	**Agile**	**Fit**
Flexible and efficient – Individualised products					*
Flexible – Small batches				*	
Efficient – Large batches			*		
Inflexible – High volumes		*			
Inefficient – Small batches	*				

Table 3.1: The evolution of fit manufacturing

Pham et al. (2008, 2011) stressed that it is the integration of a company's manufacturing operations with its business strategy and its technological capabilities that is required to enable it to achieve sustainable growth. Fit manufacturing avoids creating a fragmented and complex operational environment that often arises when companies incrementally implement various manufacturing paradigms (TQM, lean, agility, etc.) in a sequential manner. In addition, the integration of the various manufacturing strategies helps to remove the overlapping that exists between lean and agile manufacturing. Fit manufacturing does this by specifically targeting areas of overlap for development.

Previous attempts at integrating leanness and agility have led to the birth of initiatives such as the 'leagile' or 'agilean' paradigm (Naylor et al., 1999; Mason-Jones et al., 2000a); this paradigm appears to be largely confined to supply chain management and not the production system. Also the leagile paradigm does not involve the integration of economic sustainability nor extends into the realm of production system management. Thus, the current effort at integrating lean and agile manufacturing with economic sustainability evaluates the production system ability at meeting and overcoming the challenges of today and those of the future. The requirement for such a holistic manufacturing strategy is further underlined by Bryan and Farrell (2008) who stressed the need to shape the long-term future of manufacturing firms. Table 3.2 illustrates the differences in deliverable benefits between fit and older manufacturing approaches.

Manufacturing Approach	Benefits
Lean Manufacturing	Reduced production and inventory waste Increased value-adding processes Improved products and processes Reduced production cost
Agile Manufacturing	Reduced time to market Improved manufacturing flexibility and process re-configurability Creation of virtual partnerships
Fit Manufacturing	Integrated improvement initiatives Holistic manufacturing strategy Increased enterprise fitness Economic sustainability

Table 3.2: Differences in deliverable benefits between fit and older manufacturing approaches

Other researchers whose work has touched on the concept of ‘fitness’ include De Wit and Meyer (2005), and Found and Rich (2006). De Wit and Meyer (2005) viewed a firm’s fitness as its competence to perform in a particular field. They argued that a firm possesses a competence if it has the ‘knowledge, capabilities and attitude’ needed to successfully operate in a specific area. Knowledge was defined as the sum total of rules and insights that can be extracted from information and made use of. Such knowledge includes ‘market insights, competitive intelligence, technological expertise and understanding of political and economic developments’. Capability was described as the organisation’s potential or ability to use a combination of skills necessary to carry out a specific activity or activities. Examples of a firm’s capability base include market research abilities and advertising and production skills that if combined together could result in new product development. Attitude was referred to as the mindset prevalent within an organisation which characterises how the organisation views and relates with the world. An organisation’s attitude for example can be quality-focused, internationally oriented, innovation-biased or competitively-aggressive.

On the other hand, Found and Rich (2006) described fitness as being concerned with leanness, agility and the ability to convert materials at the least cost. The authors linked economic sustainability with the concept of ‘fitness’ and argued that economic sustainability concerns the ability of business managers to extract a profit and invest it within and outside the firm. These investments were termed ‘fitness investments’. They were seen as necessary to enhance the firm’s capabilities for the conversion of inputs into outputs (*efficienc*y) or ‘fit’ of the firm in customer and supply markets (*effectiveness*). This argument viewed organisations’ longevity and economic sustainability (*viability*) according to their ability to invest and create the right capabilities. However, this viewpoint expressed by Found and Rich (2006) has limitations in that in reality a company’s ability to survive in the long term is driven by multiple factors including its ability to adapt to a changing landscape, identify new opportunities and align manufacturing operations to take advantage of them and be aware and plan ahead of potential disruptions. In addition, it is important to note that fit confers on manufacturing firms the ability to determine their preparedness for long-term prosperity by integrating the goals of a sustainable future with operational efficiency.

However, it should be noted that some threads of the arguments put forward by De Wit and Meyer (2005), and Found and Rich (2006) on fitness converge to a similar viewpoint expressed here that an organisation’s competence plays an important role in determining its long-term success. This viewpoint reveals that, in practice, characteristics of fit manufacturing are already seen in industry and that components of the philosophy can be integrated into a winning strategy.

3.6. Structural Characteristics of Fit Production Systems (FPS)

The concept of evolved ‘adaptability’ demonstrated by coyotes is closely associated with this fitness theory. Fit manufacturing encourages firms to stop being ‘wolves’ in the struggle for long-term survival and develop greater adaptability skills. Most firms failed because of economic upheavals for which they are not well prepared or because of the fact that they are unable to adapt to changes or a combination of both. In the business environment, such changes might require greater flexibility and innovation in addition to cost control. Manufacturing firms need to develop mechanisms that promote ‘self-perpetuation’. Self-perpetuation is possible through ‘innovativeness’ and ‘self-renewal’. Innovation is a creative process which represents the ability of the firm to reach out creatively beyond current operational and products offerings in the processes of learning, development and evolution. On the other hand, self-renewal represents the ability of the firm to continuously renew itself while maintaining the integrity of the overall organisational structure.

Organisations such as the Digital Equipment Corporation (DEC) and the US financial firm, Bear Sterns, failed not because they were unable to innovate, create competitive quality products or control production cost, but because they were victims of upheavals which they could not cope with due to their low level of fitness. Such upheavals, when internally or externally induced, rendered the ‘immune system’ of the organisation ineffective, thus causing its subsequent collapse. An organisation’s long-term fitness depends on its ability to sustain its success. Once this ability is eroded, a fit organisation can quickly become a failed organisation. Fit firms make use of self-perpetuation strategies to 'maintain and expand their identity, while resisting the pressure directed toward '*static stability*'.

Under fit manufacturing, '*self-perpetuation'* is described as the ability to continuously renew and reinvent the organisation towards greater goals of economic sustainability and fitness. It gives the organisation greater flexibility at using existing knowledge within its boundaries to create new generation products. Such an innovative approach has helped Apple, for instance, to build a niche for itself in consumer electronics. In the fields of personal computers, digital devices and mobile telephones, Apple has demonstrated the ability to invent new industries and reinvent old ones. This because through an innovative process, Apple is ability to reach out creatively beyond physical (technologies and systems) and mental (innovations) limitations in the processes of organisational evolution and creation of sustainable performance. Other innovative organisations demonstrate this by their ability to generate new knowledge in the forms of intellectual properties (IP) or new products. For example, 3M is a company whose evolution started with mining stones from quarries for use in grinding wheels. Today, the company is known for its innovativeness through the thousands of products it has brought to the market.

Other elements of fitness such as leanness and agility are required to impart the values of rapid adaptation to growing demands and to compete simultaneously on the basis of production cycle time, price, quality, customisation and an effective supply chain.

3.6.1. Components of Fit Production System

Before a manufacturing firm can be described as fit, the firm must be able to exhibit the five core components of a fit enterprise described in the above section and depicted in figure 3.2 below. The figure indicates that a FPS is driven by the simultaneous development of a company's long-term strategic continued existence (sustainability) and operational competitiveness (leanness and agility). Integrating the various elements of production systems is crucial so that they can work in concert together to achieve greater effectiveness and competitiveness. A familiar example of an integrated manufacturer is the British aerospace and defence company, BAE Systems. BAE does not manufacture in-house the military hardware it sells to its customers in 100 countries. BAE outsources the design, prototyping and manufacturing aspects of its contracts to its partners, while retaining the competence to control and coordinate the supplier network and integrate the different supplier components together to function as required. The company makes use of a product order customisation process which enables it to meet the various demands of its customers scattered across the globe. This means that the company does not actually purchase components and assemble its technically

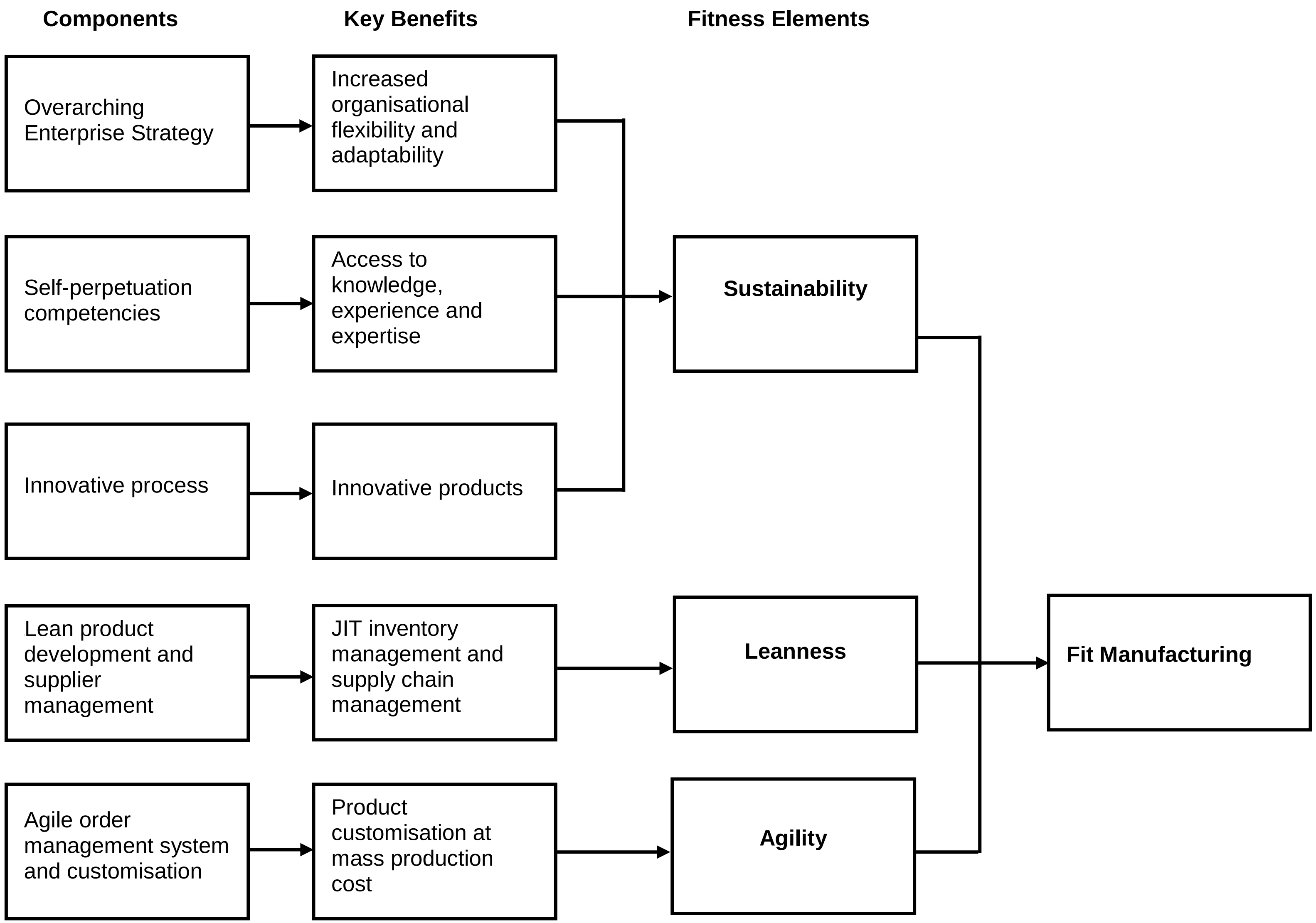


Figure 3.2: Components of fit manufacturing system

advanced products until it has received a request from the customer. It also means that the company can sell directly to customers thereby eliminating potential cost-adding processes involved in indirect sale. This type of business model is also practised by other manufacturers including Dell Computers.

3.6.2. The 6 P’s of Fit Manufacturing

Organisations striving to be fit will have to put in place an overarching enterprise architecture described above. This enables the organisation to be flexible and adaptable to change. The fit enterprise architecture also acts to deliver self-perpetuation strategies that offer the organisation the ability to discover and access the different levels of knowledge, experience, and expertise that lie inside and outside its boundaries. The overarching architecture also enables the organisation to reach out creatively through a lean product development and supplier management process, and an agile order management system that supports build-to-order production. These elements of fit enterprise interact dynamically to influence the ability of the firm to evolve, grow and sustain itself over time. Thus *a fit firm is a sustainable firm that is lean and agile* (Adebayo-Williams, et. al., 2007).

In addition to the overarching fitness architecture, organisation striving to be fit will have to make informed choices and commitment towards the 6Ps of *people, product, process, partnership, place,* and *profit* (Adebayo-

Williams, et. al, 2007). These are critical success factors and act as categories that help to detail areas that are important to meeting today’s manufacturing challenges and also crucial to the long-term growth of the firm and its survival. An organisation determined to be sustainable and fit must make strong commitment to ***people*** in order to develop strong employee links required to achieve both short-term and strategic long-term goals. This means recognising that the continuous development of the entire workforce, both management and subordinates, and everyone within the organization’s supply and distribution chain contributes towards achieving the organisation’s long-term economic survival.

An organisation striving to be successful and sustainable in today’s competitive and dynamic market environment must focus on its ***products*** or services. Focusing on product offerings requires ability to maintain a balance between product performance, in terms of quality and reliability and (technical) innovation in terms of functionality and cost. Equally important is the time to introduce new products so as to achieve time-to-market profitability (Lu et al., 1999). The product creation ***process*** is concerned with creating and adding value in the forms of products and services through the transformation of a range of inputs such as people, land, machinery, IT infrastructure, business process strategies and raw material. The value created must meet the needs of sustaining the future of the business through sales and profit, and that of the customer through quality products and services, at the right time, at competitive price. In the age of rapid technological advancement, with the effect of declining product life cycle coupled with the boom in out-sourcing and job movement from Western economies to lower cost economies, the development of strategic ***partnerships*** in the form of collaborative manufacturing, contract manufacturing and out-sourcing will be crucial in determining the economic survival and sustainability of manufacturing firms (Sturgeon, 2002). The ability to form strategic alliances will play vital role in the journey towards sustainable future of manufacturing firms.

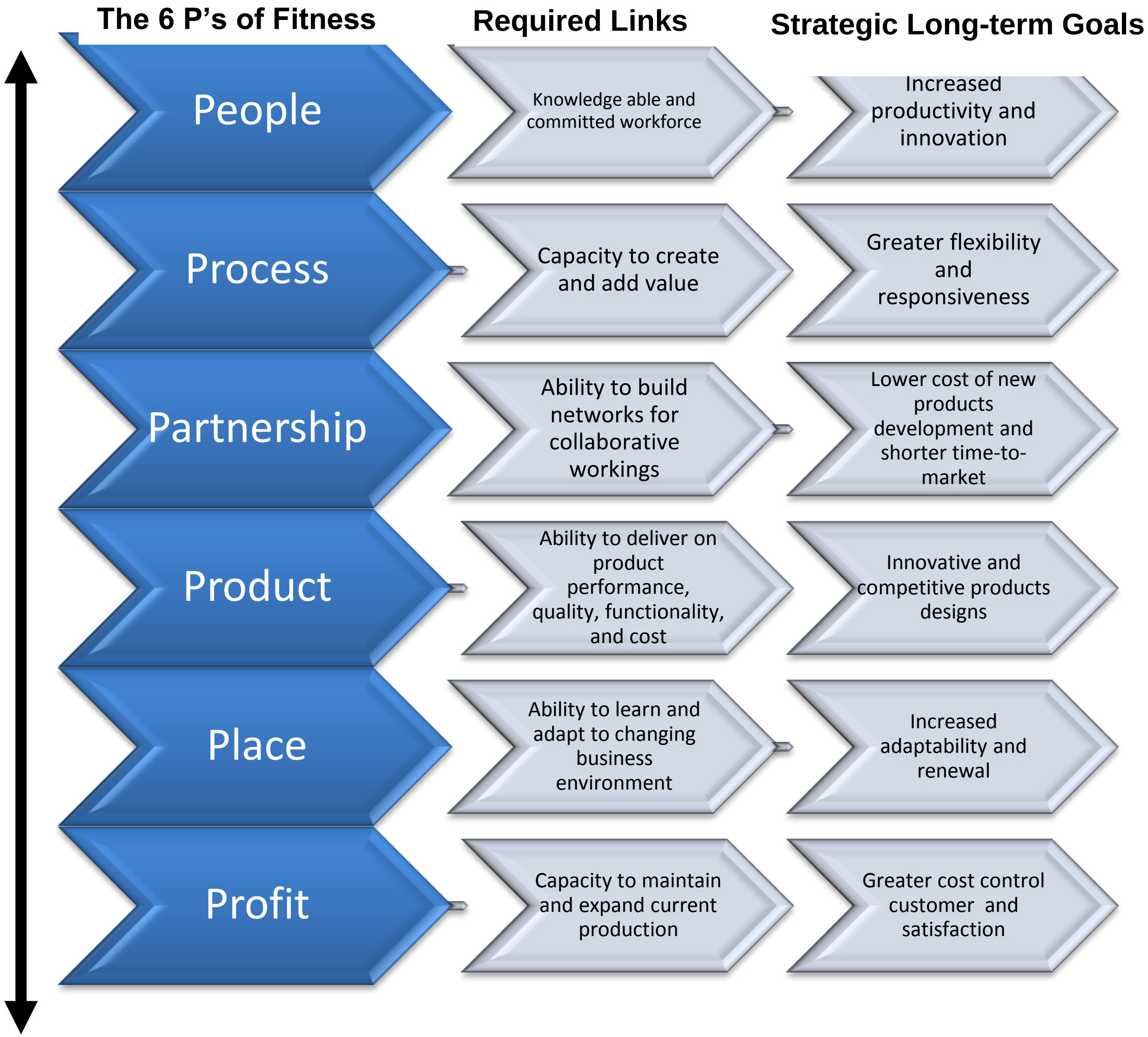
With greater prominence being placed on the manufacture of products in lower labour cost countries, a manufacturing organisation must consider seriously the global positioning of its design, manufacturing and sales departments. In today’s global environment and with the use of increasingly sophisticated web- based systems a company does not have to have all its business functions in one place and it may decide to move its manufacturing operations to a labour efficient country whilst retaining its intellectual property (its design departments etc) closer to its core business point. ***Place*** is therefore a key consideration. The strategic placement of a company’s manufacturing operations is also important from an environmental perspective and this will become increasingly important to companies in the future whilst maintaining the need for a strong focus on the bottom-line results and profits (Interface, 2007).

Paying attention to the environment represents the organisation’s ability to learn and adapt while remaining in harmony with the world around it, enabling the organisation to be able to react in a timely fashion to the conditions of the society surrounding it (De Geus, 1997). ***Profit*** is a crucial indicator of economic sustainability. Contributors to sustainable profits include good customer service (before and after sales), customer retention, continued patronage and brand loyalty, customer satisfaction, so also is the ability to create innovative value that meet and exceed customer needs and expectations (Adebayo-Williams, et. al., 2007). The 6Ps of fit manufacturing are illustrated in figure 3.3.

3.7. Advance Warning Mechanism – A Mechanism for Increased 'Fitness'

To deal with today's intensified competition, market turbulence and changing customer demands, fit manufacturing advocates developing a company's capability that promotes fully adaptable manufacturing. This is possible by integrating market intelligence with the manufacturing system using an AWM. The mechanism provides manufacturing firms with the ability to create a dynamically stable enterprise that is optimised and can respond in a timely manner to changes in consumer demands, expectations and values. The development of the AWM requires that marketing and sales people become aware of the capabilities of the firm and act as a 'product gatekeepers' when out in the field (Pham et al., 2008). These capabilities include the competencies in product research

Figure 3.3: An illustration of the 6Ps of fit manufacturing



The 6 P's of Fitness	Required Links	Strategic Long-term Goals
People	Knowledge able and committed workforce	Increased productivity and innovation
Process	Capacity to create and add value	Greater flexibility and responsiveness
Partnership	Ability to build networks for collaborative workings	Lower cost of new products development and shorter time-to-market
Product	Ability to deliver on product performance, quality, functionality, and cost	Innovative and competitive products designs
Place	Ability to learn and adapt to changing business environment	Increased adaptability and renewal
Profit	Capacity to maintain and expand current production	Greater cost control customer and satisfaction

and development, product manufacturing and customisation, technical expertise, specialised knowledge and other resources necessary to capture and exploit new opportunities at minimal cost and in a timely fashion.

Accordingly, manufacturing companies aiming to be fit must be able to recognise forces shaping their industry such as transformation in technology, customer demands and global trends, transition in the marketplace, government policy and in the socio-political landscape and near-future turmoil in global financial health. In addition to developing the capability to anticipate and understand emerging change, fit firms must also possess the ability to catalyse transition from planning to action while preventing non-synchronised behaviour. Beyond the role of product-gatekeepers, marketing and sales people need to be trained in identification of key early warning signals for market transition or deterioration in the competitive landscape.

An organisation's long term economic sustainability and fitness is determined largely by its ability to put in place an effective AWM for correctly reading and understanding the signs of changing business landscapes before they impact both the short-term and long-term objectives of the business. AWM gives such advantages by offering extra capability to manage strategic issues. It encourages manufacturing firms to be proactive and take advantage of changing forms of market opportunities, threats and competition that emerge once the potential destabilising forces of economic un-sustainability are unleashed either by society, the industrial landscape, the competition, or a combination of any of these.

Table 3.3 is an illustration of the forces driving change and their implications on the sustainability of manufacturing firms. For example, the current turmoil in the global credit market has shaken manufacturing to its foundation. However, with the aid of an AWM a manufacturing firm should be able to project the nature of the emerging economy and competition. At the same time, the demise of manufacturing firms during this period offers fit firms the opportunity to increase not only market share but also to enter into new markets that will be left void by the exit of failed firms. As the current credit crisis intensifies and a new form of consumerism emerges, fit firms must have the capacity to switch from ‘build-to-forecast’ to ‘build-to-order’ or a combination of both as a tool for volume management in production. This calls for an agile order management system that is very flexible with respect to market shifts and demands.

Driving forces	**Potential Implications**	**Potential impacts on long term fitness and change in business strategy**
Transformation	Transformational forces drive new developments and initiate the need for change within the system	Transformational forces are frequently associated with period of marked changes and alterations in business forms. This is often characterised by downsizing, diversification, technology advancement or the need to improve overall business efficiency.
Transition	Transitional forces drive conversion and initiate movement from current state to a new state	This can be associated with the passage from one form, state or entity to another. This development is often characterised by business merger, acquisition or modification in the business configuration
Turmoil	Turmoil forces signal the development of precarious situations	This is frequently associated with periods of uncertainty. Potential warning signals to look out for include massive job losses, corporate deaths or extensive industry restructuring.

Table 3.3: Forces impacting manufacturing firms’ fitness

3.8 Operational Characteristics of Fit Production Systems (FPS)

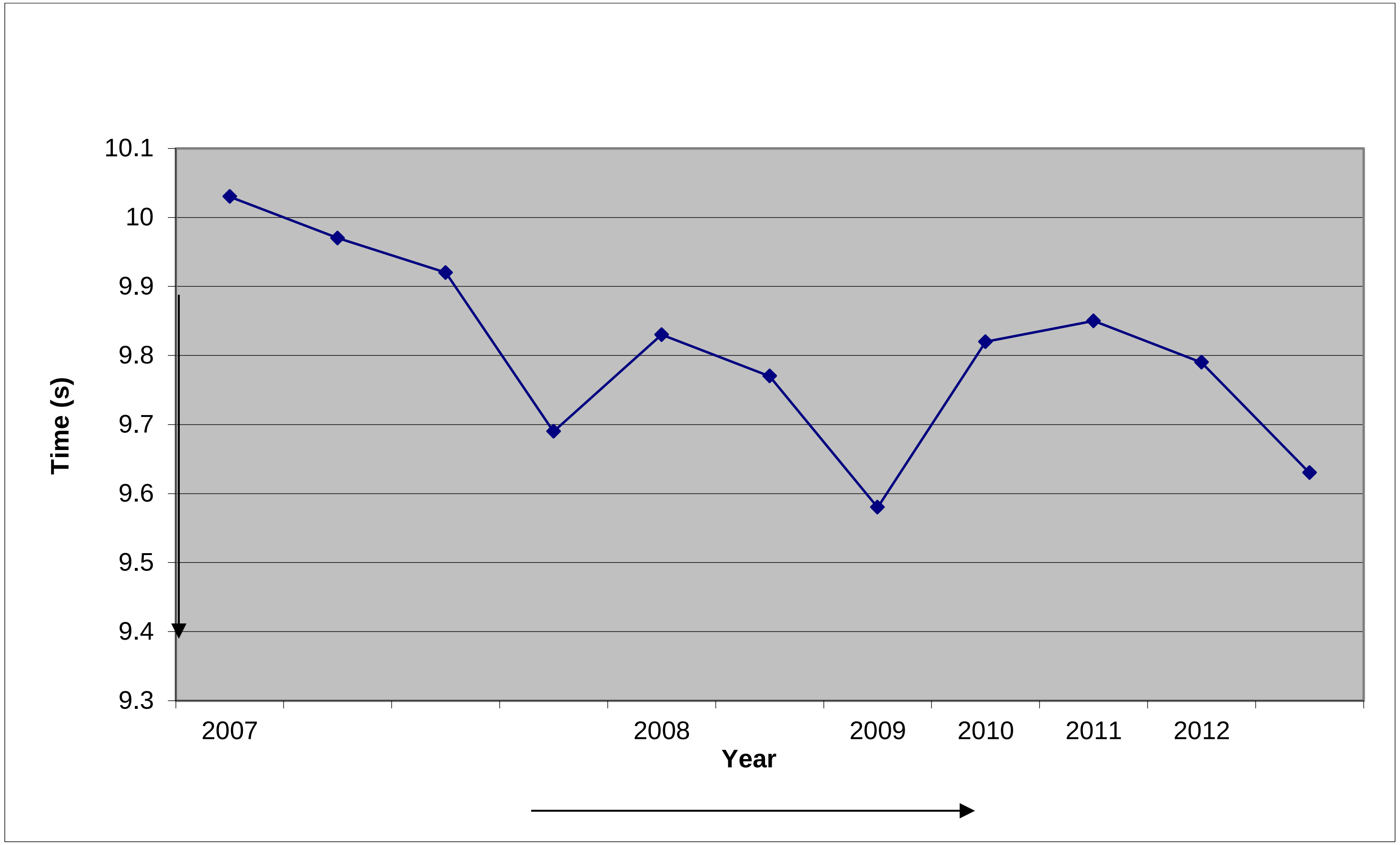
The fit hypothesis states that a fit system is one which, when subjected to a step change or continuous change induced internally or externally by a combination of forces (transformational, transitional and turmoil), the system is able to cope with the change and adjust itself overtime without suffering a sustained decline which could lead to total failure. The time it takes for the system to adjust to the step change or continuous change was argued to depict the organisation's fitness level Pham et al (2011). This definition of fitness suggests a fit manufacturing firm is one that possesses certain dynamic characteristics that are crucial for the business long-term viability and sustained performance.

However, problems persist with defining and measuring fitness and the overall generality of the fit model. Is it possible to state in terms which are clearly definable and measurable the conditions which are necessary and sufficient to bring about fitness change? One way to overcome this is to make use of analogical review of a top athlete fitness performance. Such a study can be utilised to understand how an athlete achieves performance fitness necessary to win a race. The outcome of the analogical review can then be utilised to derive the operational characteristics of firms firm. More so, such an analysis could give further insight into the *dynamic conditions* that shape fitness.

Sprinters seem particularly suitable for fitness set analysis. For instance, sprinters typically undergo intensive training to develop techniques and skills required to gain competitive edge, stride frequency, speed and stamina, balance and flexibility, physical superiority and improved start to races. The sprinter who is able to deliver optimised performance and perhaps break new speed barrier in 100m for example is often named “the fastest man or woman in the world”. Staying injury free also plays important role in individual fitness and ability to achieve the ultimate goal. If the athlete does not practice frequently, he will not be able to develop the discipline focus required to compete, thereby increasing the probability of achieving sub-optimal performance, reduced flexibility, reduced speed and reduced stamina. Likewise, over exposure of the athlete to all manner of sprinting competition could also increase the athlete vulnerability and reduce the chances of long-term career. Hence, athletes strive to achieve and maintain a healthy body mass index which gives maximum fitness to the individual.

Figure 3.4 shows the 100m progression for the sprint star, Usain Bolt, a three-time World and Olympic gold medallist. Usain Bolt started out as a cricket and football player before his potential as an athlete was discovered and developed. Prior to 2007, Bolt preoccupation as a sprint star was primarily 200m events and 400m races. However, in 2007 Bolt rain his first 100m race setting a personal best of 10.03s. Bolt continued to develop in the 100m and considerably preparing himself better for competition. A year after his first 100m race at the 2008 Beijing Summer

Figure 3.4: Usain Bolt 100m Progression



Olympics final Bolt set new 100m World Record of 9.69s, a record he latter improved upon at the 2009 World Championships with a time of 9.58s. At the same championship, Bolt also set new World Record for 200m race with a time of 19.19s, an improvement over his World Record performance of 19.30s at the Summer Olympics. In interviews granted before the 2012 Olympics, Bolt pointed out that he hopes to lower his 100m World Record to 9.40s (Maidment, 2012). Given the shape of figure 3.4, the fitness performance of a top athlete, a revised research hypothesis for fitness is proposed.

Revised Research Hypothesis:

> *It is assumed that over a period of time fitness outcomes take the shape of an “S Curve” when depicted graphically. This statement implies fitness is a function of time and not an end state. The slope of the fitness curve for a company indicates whether its fitness level is increasing, decreasing or static. A negative slope signals a decline in the overall health of the business. If this were to persist, it would eventually lead to failure of the company. Thus a fit system is one which, when subjected to a step change or continuous change induced internally or externally, is able to cope with the change and adjust itself overtime without suffering a sustained declined which could lead to a total failure. Fitness Index is therefore defined as the output of a manufacturing company against leanness, agile and sustainability performance enablers.*

The operation of a manufacturing firm continually generates new fitness scores against which its long term economic sustainability is assessed. This helps the organisation to evaluate its future prospects of survival.

3.8.1. Operational Rule Base for Fitness

Using the inference method of backward chaining, it is possible to deduce from the experience of top class sprinters a rule base for fitness, in order to abstract necessary and sufficient conditions for the phenomenon. Backward chaining is the inference method whereby, the process of inference is preceded by choosing a goal to be proved and then looked for rules that will help establish the goal (Psiaki, 2005). This form of goal directed reasoning has been applied in a number of expert systems applications (Rusell and Norvig, 2009).

Using the top athlete example stated above, and working backward from the consequent to the antecedent – top athletes performance fitness is comparable to a fit system; the following rules for fitness can be deduced:

1. If X is a living entity – Then X is goal driven

2. If X is healthy and has stamina – Then X can compete

3. If X is not static in motion – Then X has measureable and controllable performance

4. If X can overcome existing barriers and boundaries – Then X is innovative

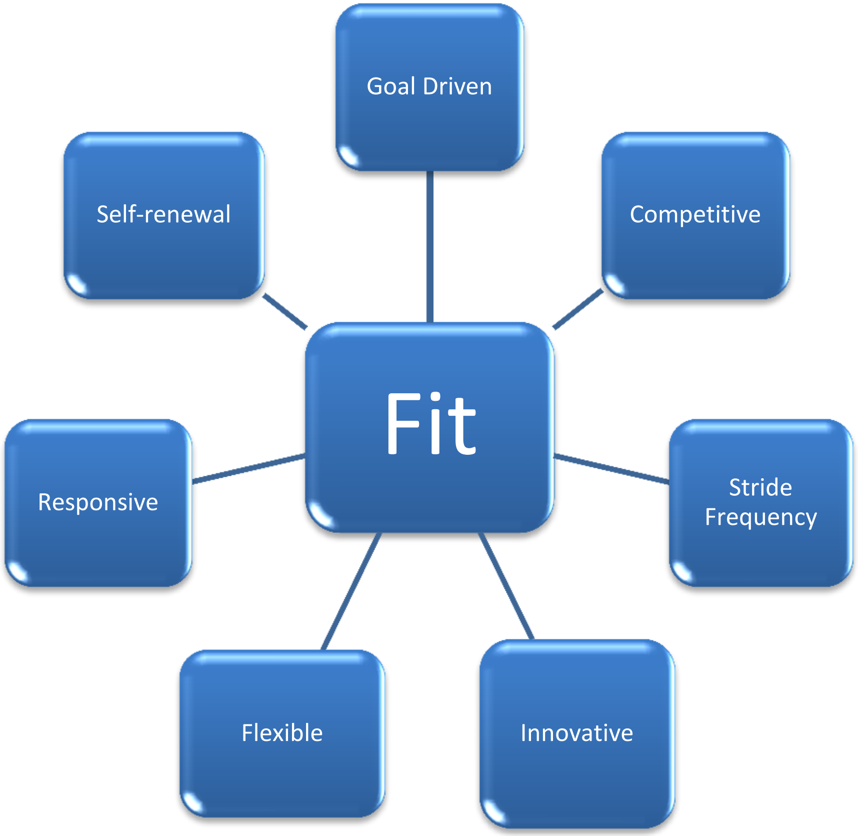
5. If X has a range of motions – Then X is flexible

6. If X can modify and enhance its muscle fibre strength – Then X is responsive

7. If X can maintain the integrity of the overall structure – Then X can keep performing at athletic best and capable of renewing self.

From the seven rules described above, the antecedent of the rule base provide support in determining the nature of fitness, that is – a fit entity is a living entity that is healthy, not static, capable of overcoming limitations, can modify its performance using a range of motions while maintaining its overall structural integrity. Given that the consequences matches the goal of determining the intricate nature of fitness, thus, a fit system can be described as goal driven, competitive with measurable and controllable performance, is innovative, flexible, responsive, and capable of self-renewal. Figure 3.5 is an illustration of the intricate nature of fitness.

Figure 3.5: Attributes of competitive fitness



3.8.2. Attributes of a Fit System

Using the rule base defined at section 3.8.1 the followings can be inferred as attributes of a fit system:

i. **Goal focus**. A fit firm is goal driven in manipulating inputs to obtained desired output. This means creating a unified vision for the organisation and a focus on the whole (Drucker, 1988) shared by all in the organisation. This condition of fitness is supported by the argument of Collins and Porras (1994) described in their famous work - Built to Last.

ii. **Competitive**. This condition of fitness affirms that fit firms compete not on the basis of their ability to implement improvement programmes, such as JIT (Just-in-Time) production, TQM (Total Quality Management), and Agile manufacturing but rather on the skills and capabilities that enable a factory to excel and defend its competitive advantage (Haynes and Pisano, 2000).

iii. **Stride frequency**. This property describes the ability of a fit system to replicate successful outcomes and continuously outperform itself while staying ahead of competitive challenges in the marketplace. Stride frequency drives an organisation’s performance forward with the focus of increasing the organisation chances of exceeding previous performance output. The time it takes for an organisation to move from one successful performance to the next is an indication of its stride frequency. In order words, it is the rate of growth or positive change within the business.

iv. **Innovative**. This property describes ability of a fit firm to reach out creatively beyond current limitations in the processes of learning, development and evolution (Pham et al., 2011). Skills and capabilities become important when they are combined in unique combinations which create strategic value that can contribute to the manufacturing firm's ability to overcome barriers (Grant, 1991).

v. **Flexible**. A fit firm has the capability to achieve balance, adaptability, and coordination with minimal resources. Ebrahim (2011) suggested that flexibility improves balance and balance affect the agility of a firm. Volberda (1997) pointed out that organisational flexibility is considered a strategic option in situations in which anticipation is impossible and strategic surprise likely. The author stresses that both manufacturing and innovation flexibility requires a structure of multi-functional teams, a technology with multi-purpose machinery, universal equipment and managerial capability.

vi. **Responsive**. Fit firms can adapt rapidly and cost efficiently in response to changes in the business environment, and are capable of seeking out new demand and growth to create products of the future (Pham and Thomas, 2006).

vii. **Self-renewal**. Fit firms are capable of continuously self-renewal while maintaining the integrity of the overall structure of the enterprise. They are capable of repeating successful performance without getting sucked in the past or present. Fit firms do this through building sustainable manufacturing systems that are creative, flexible, and capable of innovate and persistent improvements. The drive for renewal pushes fit companies to continually experiment with new ideas and solve problems that other companies are yet to recognise, and build structures that will help them survive (Pham et al., 2008).

3.8.3. Fit Manufacturing – A Hypothetical Case

For example, a loss in market share suffered by a certain company A due to a successful introduction of a technologically superior product by a major competitor can be viewed as representing a transitional change in the underlining product technology. The successful product launch by the competitor also signals a need for change within company A’s product design department. Ignoring such a signal can eventually lead to company A falling behind and, in some cases, its future financial anguish.

An example of this type of company is GM once the largest car manufacturer and industrial company in the world. GM failed to recognise its vulnerability to fuel-efficient Japanese cars, even though this vulnerability was first exposed by the 1970s oil crisis. The company's failure to control production cost per vehicle coupled with its inability to adjust quickly to changes in customer demands for fuel-efficient cars over time cost GM almost lethal damage just three decades later. While Toyota was ramping up sales of fuel-efficient cars, GM was still relying on the production of fuel-hungry pickup trucks and SUVs. The inability on the part of GM to adapt rapidly to a changing landscape reduced its profitability and eventually led to its bankruptcy in 2009. GM's failure was due to a lack of flexibility in its manufacturing system and its low fitness level.

From the above scenario and the preceding hypothesis, it is further postulated that the time it takes for a system (a manufacturing firm) to adjust to a step change or continuous change can be assumed to depict the organisation's fitness level. Figure 3.6 is a graphical illustration of the 'fitness' and behaviour exhibited by four hypothetical manufacturing companies A, B, C and D when subjected to a major sudden loss in revenue.

From figure 3.6 it can be seen that company D went from being the best performer, gradually into deficit and then to bankruptcy because of the company's inability to adapt to a significant and sudden loss in revenue.

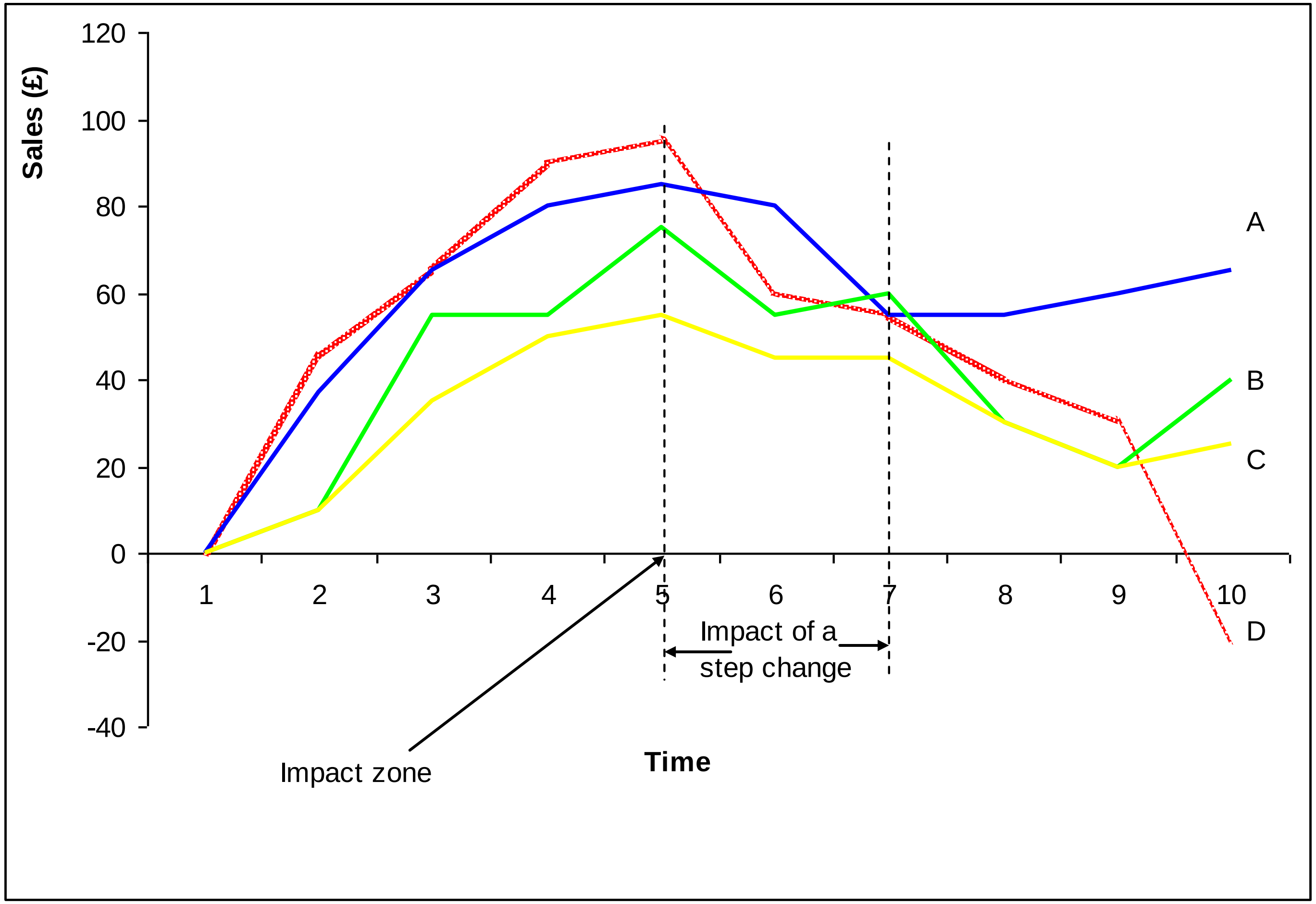


Figure 3.6: Illustration of 'fitness' hypothesis

On the other hand, company A represents manufacturing firms like Toyota which, although negatively affected by losses in revenue as being witnessed now in the auto industry, are still able to withstand such ‘step changes’ without putting at risk the overall health of the company. Such manufacturing companies are able quickly to put in place manufacturing strategies that will help them to withstand the storm and gradually return to positive growth. Companies B and C represent typical manufacturing firms that are daily fighting the battle for survival and continually implementing restructuring plans. They are companies whose long-term economic sustainability is questionable due to the high levels of inefficiencies inherent in the manufacturing model. These companies occasionally do exhibit good performances but are unable to sustain them. Perhaps, for such companies to improve their fitness levels and long term economic sustainability, they need to investigate the manufacturing strategies of company A and try to integrate such practices into their manufacturing model. Examples of companies B and C are Saab and the Russian company, Gorky Automobile Plant (GAZ).

Table 3.4 provides a summarisation of the distinctions between the manufacturing strategies of lean, agile and fit. From the table, it can be seen that clear differences do exist in the underlining philosophy, architecture and competitive benefits that these three manufacturing strategies represents.

	Manufacturing Strategies		
Distinctions	**Lean**	**Agility**	**Fit**
Underpinning Philosophy	The core idea behind lean thinking is to maximise customer value while minimising waste.	Agility is the ability to thrive in an environment of continues and unpredictable change.	Fit aims to integrate short-term incremental operational goals with long-term economic survivability in order to create a sustainable enterprise
Foundation	Lean manufacturing paradigm began in Japan in the 1950s and was incrementally developed by Toyota in attempt to overcome the limitations of Japanese manufacturers to implement mass production on a large scale.	The concept of agile manufacturing was developed by Americans in the 1990s in order to re-gain competitive edge over economic competitors such as Japanese –based manufacturers.	Fit manufacturing was first proposed by Pham and Thomas (2005). The manufacturing concept was described as a total manufacturing philosophy for an integrated approach to the use of leanness, agility and economic sustainability to achieve a level of fitness that is unique to a company.

Table 3.4: Distinctions between Lean, Agility and Fit

Drivers of the Paradigms	Lean is a response to competitive pressures with limited resources.	Agility is a response to complexity brought about by constant change.	Fit is a response to threat of competition from low labour cost strategies and the need to provide a integrated manufacturing strategy that is lean, agile, and sustainable.
Interest	Lean is interested in those things we can control and is value oriented to achieve a trade-off between quality and price.	Agility is interested in those things we cannot control and is time driven to achieve a trade-off between change and response.	Fit is interested in both repetitive manufacturing and un-predictable demand management, together with new market requirements
Implementation Requirements	Implementing lean entails an incremental removal of waste in all aspects of the manufacturing process and the factors underlying poor and fundamental management problems. There are seven wastes identified in the Toyota Production system.	The prerequisite for the successful implementation of agile manufacturing includes the enabling IT infrastructure and the requirement for existing business forms to become less rigid. An agile enterprise must have broad change capability that is in balance across multiple dimensions.	The implementation requirements for fit manufacturing are the identified seven conditions necessary for fitness. That is, before a production system can be said to be fit it must be goal focus, competitive with measurable and controllable performance, innovative, flexible, responsive, and capable of self-renewal.

Table 3.4 Continued: Distinctions between Lean, Agility and Fit

The Goal of Implementation	The primary motivation for lean implementation is to boost overall company performance in terms of increased efficiency (shorten lead time), productivity, enhance product quality, waste elimination and lower production cost. Lean is also interested in issues related to organisation recovery.	The main goal for implementing agility is develop capabilities for managing continuous change in customer requirements as a routine, and be able to produce ‘anything, in any volume, at anytime, anywhere and anyhow’. Agility is mainly interested in issues related to Capacity, Capability, Reconfiguration and Migration.	The main goal for implementing fit is to combine the manufacturing efficiencies achieved through leanness (standardisation and flexibility), and agility (customisation and responsiveness) with the need to build a competitive and sustainable enterprise.
Competitive Priorities	Lean focuses on cost and quality enhancements through continuous improvement in order to achieve perfection	Agility focuses on cost, delivery, quality and customisation	Fit focuses on integration of short-term operational goals of cost, speed, quality, customisation, and needs to break into new markets
Operating Architecture	Adaptability: Lean drive the cost of production down and achieve high quality products in greater variety through process flexibility.	Reconfigurability: Agility decouple cost and lost sizes, mass customise possibly in units of one at the cost of mass productions through the use of virtual communication technologies	Sustainability: Using multiple platform technologies, fit integrates systemics range of business process concepts into one model that has low operation and systems complexity
Incremental implementation	Lean is bottom-up driven, transforming the mass-production model.	Agility is top-down driven responding to unexpected change.	Fit provides a holistic view that connect all the elements of a manufacturing organisation in order for that organisation to grow and proper into the future

Table 3.4 Continued: Distinctions between Lean, Agility and Fit

3.9. Summary

This chapter has expounded the main theme behind fit manufacturing strategy. Fit manufacturing was presented as a manufacturing strategy best suited to handle the challenges of an emerging new economic where order fulfilment is not sufficient to guarantee the continued survival of the enterprise. An operational definition for fit manufacturing was also discussed using inspiration from fitness found in nature. The fundamentals of fit manufacturing were presented with discussion on an advance warning mechanism. In section 3.8 of the chapter, necessary conditions for fitness were presented which was followed by discussion on the research hypothesis and a rule base for fitness. The chapter concluded by providing a summarisation of distinctions between lean manufacturing, agile manufacturing, and fit manufacturing. In Chapter 4 attempt is made to provide a theoretical construct for the development of a measureable fitness index.

Chapter 4

Theoretical Construct for Production Fitness Measures

> *“Any intelligent fool can make things bigger and more complex... It takes a touch of genius - and a lot of courage to move in the opposite direction.”*
>
> Albert Einstein

4.1. Introduction

In chapter 3, a framework for fit manufacturing was proposed; consequently, in this chapter effort is made to present a theoretical construct for the control and performance measure of fit production system. An index is developed for each of the three sub-components of fit manufacturing system. Later on, in chapter 5 the theme of integration is further expounded by linking the manufacturing efficiencies achieved through lean and agile manufacturing with the overall business strategy of sustainability.

4.2. Fit Manufacturing: A Total Manufacturing Philosophy

The operational definition of a fit enterprise provided in Chapter 3 describes a fit firm as *lean*, *agile* and *sustainable*, and one that can compete through the creation of value that meets or exceeds customers changing expectations. A fit enterprise was described as capable of responding to improvement changes – either to fix a problem or to raise the fitness level - and adapting to environmental changes without jeopardising its overall health. This definition of fit manufacturing encompasses the scenarios under which a manufacturing system can be evaluated, assessed or considered healthy. It is therefore important to stress that fit manufacturing is neither an improvement methodology nor a cure-all strategy (solution) for whipping an organisation into shape. Rather, fit manufacturing proposes to assess, evaluate and audit the long-term fitness of a manufacturing enterprise within the context of existing manufacturing practices, and suggest areas for targeted improvement actions.

Pham et al. (2008) stressed that it is the integration of a company's manufacturing operations with its business strategy and its technological capabilities that is required to enable it achieve sustainable growth. Fit manufacturing avoids creating a fragmented and complex operational environment that often arises when companies incrementally implement various manufacturing paradigms (TQM, lean, agility, etc.) in a sequential manner. Fit can therefore be argued as a practical development that uses the principles of existing manufacturing paradigms along with new and innovative management concepts to create a sustainable approach to manufacturing. Manufacturing strategies such as lean and agility provides strategies to companies to achieve improved bottom-line savings in production terms (Thomas and Pham, 2004). However, the production efficiencies achieved through the implementation of these improvement strategies would have to be linked to product volume and demand profile in order for the firm to be successful and remain sustainable for long term. Consequently, in this chapter, an attempt is made to develop an index for each of fit manufacturing components, namely lean, agile and economic sustainability.

4.3. Fit Manufacturing: Leanness Component

The term leanness is used in the literature to describe LM performance; the literature also contains several models of leanness which have developed overtime to assess the leanness level of a company. However, there is no single leanness model that is universally accepted by all authors, more so, Womack et al (1990) did not introduce a measureable leanness index in their famous classic lean book. Therefore, most lean authors have tended to define leanness and the evaluation of an organisation's lean performance based on the context in which the improvement methodology was implemented.

Not surprisingly, leanness measurement methodologies have come in a variety of approaches with some focusing on a single leanness indicator such as elimination of waste (EW), while others examined many indicators (Soriano-Meier and Forrester, 2002). Some leanness models were also developed for specific industrial sector (Wong et al., 2009). Some other leanness models also proposed a qualitative approach (Ray et al., 2006), and some other approaches utilised a combination of qualitative and quantitative measures. Furthermore, some leanness measures were based non-financial indicators and financial performance measures. Fullerton and Wempe (2009), examined the relationship between non-financial manufacturing performance measures and lean manufacturing/financial performance (profitability). Zanjirchi et al., (2010) developed a methodology for measuring leanness degree of manufacturing companies using fuzzy logic, while Vinodh and Chintha (2009) implemented a leanness measurement model using multi-grade fuzzy approach.

In trying to explain the various approaches adapted to leanness evaluation, Shah and Ward (2007) attributed this inconsistency to multiplicity of descriptions and terms used to describe lean production. The ambiguity in lean assessment, Shah and Ward (2007) claimed, stems from lack of clear agreed-upon conceptual definition of the production methodology. On the other hand, Cua et al., (2001), asserted that variation in approaches is due in part to the piecemeal implementation of the production philosophy adopted by managers. While, Hendricks and Singhals (2001) work on total quality management (TQM) suggested that contextual factors impact methodological inconsistencies. Ultimately, what emerges from the literature is a common agreement, among all lean practitioners and researchers that knowing a company’s leanness performance is useful to enable the company take necessary steps to improve its operational and manufacturing strategies.

To solve the problem of inconsistencies associated with measuring organisational leanness, Shah and Ward (2007) suggested clarifying the conceptual definition of lean production. For instance, lean manufacturing has been frequently defined as a manufacturing strategy that focuses on waste elimination by streamlining the processes and facilitating cost reduction (Hines and Rich, 1997; Worley, 2004; Wong et al., 2009). The authors defined LM as a manufacturing strategy focusing on elimination of waste. Seven deadly wastes associated with lean manufacturing are namely:

- Overproduction
- Over processing
- Waiting
- Transportation
- Defects
- Inventory
- Storage

Liker and Wu (2002) defined lean as a manufacturing philosophy that focuses on delivering the highest quality product on time and at the lowest cost. Hopp and Spearman (2004) defined lean production as an integrated system that accomplishes production of goods/services with minimal buffering costs. LM has also been defined as an integrated system of inter-related elements and management practices including Just-in-Time (JIT), quality systems, work teams, cellular manufacturing, continuous improvement, pull production, etc (Shah and Ward, 2003).

This LM definition was later reviewed with a simple as “an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability” (Shah and Ward, 2007). Both the former and the later definitions encompass the production philosophy and its components. Lean production is generally described from two points of view (Shah and Ward, 2007):

- As a production philosophy: this is the theoretical perspective whereby lean production is seen as a set of guiding principles with overarching goals (Womack and Jones, 1996; Spear and Bowen, 1999)
- As a set of management practices: this is the operational perspective of lean, whereby the manufacturing strategy is seen as a set of management practices, tools, or techniques that can be applied to improve the production process (Hines, et., 2004, Hasle et al., 2012, Hu, 2012).

However, whatever definition or perspective is adopted it is safe to assume that LM has both input and output dimensions. Hence, the definition proposed in this study focuses on both the input and outputs elements capturing the fundamental essence of lean manufacturing:

> *Lean is a manufacturing strategy that contributes to the overall fitness of the firm through waste elimination, quality improvement, and cost control.*

The simple above stated definition captures the basic criteria that every company must operate in order to achieve a level of leanness. In addition, this definition reflects the competitive advantages of Quality-Cost-Delivery (Wan and Chen, 2008). Regarding delivery, Sarmiento et al. (2007) argued that a higher internal quality can lead to both higher on-time delivery rates and higher external quality levels. The authors asserted that a compatibility situation between delivery reliability, internal quality, and external quality (after-sale quality) were reported by several studies (Morita and Flynn, 1997; Samson and Terziovski, 1999; Safizadeh et al., 2000). In addition, the LM definition above reflects dimensions of the traditionally accepted competitive priorities in manufacturing environment, namely: cost, time, innovativeness, quality and flexibility (Boyer and Lewis, 2002; Safizadeh, Ritzman, Sharma, and Wood, 1996; Skinner, 1974). Hayes and Wheelwright (1984), and Koufteros et al. (2002) argued that in manufacturing environment, competitive priorities represent the strategic business objectives and goals, and are executed through operational actions plans.

4.3.1 Key Criteria of the Proposed Leanness Index

Considering the overall objective of this study, which is to develop a simple easy to use fitness index that reflects the three defined dimensions of the concept, a leanness index is proposed with the following requirements:

i. **Simplicity**. In this, emphasis is on ensuring that the leanness index captures the essence of simplicity and ease of use without adding an extra layer of complexity. A simple measure is more easily understood and easier to explain, more so, simple measures usefulness are apparent.

ii. **Objectivity**. By this, the leanness index should be quantifiable, and measurable, as opposed to subjective criteria. This eliminates human bias in judgement as all data used will be natural numbers.

iii. **Integrative**. The proposed leanness index should reflect dimensions of competitive priorities of Quality-Cost-Delivery (QCD), assuming that higher internal quality is directly proportional to on-time delivery rates.

iv. **Universality**. The leanness index can be extended and applied across industrial sector. This ensures that the leanness index can be used for all companies to compare with each other.

v. **Scalable**. Since the objective is to measure the degree of leanness of a manufacturing process or an enterprise, it is proposed that the leanness index will use a scale of 0 to 1 rather than absolute numbers

4.3.2. Leanness Index Derivation

The body mass index (BMI) is frequently used for estimating human body fat based on an individual's weight and height. Apell et al. (2011) defined body mass index of an individual as the relationship between a person's body mass divided by the square of his or her height. Essentially, BMI is determined using the formula below:

$$BMI = \frac{\text{Mass(kg)}}{(\text{Heigh(m)})^2} \qquad 4.1$$

Conversely, Leanness Index (LI) is estimated using the definition of LM established at section 4.3. Having in mind that the main objective of LM is elimination of waste (EW), thus, a company's level of leanness can be determined by the amount of waste or excess in the factory capacity relative to sales performance. This expression is written as:

$$LI = \frac{\text{Sales(\$)}-\text{Rejects(\$)}}{\text{Installed Capacity(\$)}+\text{Inventory(\$)}} \qquad 4.2$$

Where:

$$0.00 < LI$$

Following from equation (4.2):

***LI* = 0.00** means zero sales quantity

LI* = 1.00** means installed capacity and inventory equal net sales quantity, a state of 'perfect leanness***'

***LI* < 1.00** means increasing excess capacity

- Reject is defined as the current month figure of the combination of scraps produced during steady state production and sales returns due to defects i.e.

$$\text{Rejects} = \text{Scraps} + \text{Returns} \qquad 4.3$$

Note that Rejects cannot be greater than the combination of installed capacity and inventory because the most units that can be rejected is the installed capacity and the inventory at hand

$$\therefore \qquad \text{Rejects} \leq \text{Installed Capacity} + \text{Inventory} \qquad 4.4$$

- Scraps are defects produced during the production process

- Returns are sales refunds to customer for returned goods

- Sales is defined as the total sales quantity for the month i.e.

$$\text{Sales} = \text{Total Quantity Sold} \qquad 4.5$$

$$\text{Sales} \leq \text{Installed Capacity} + \text{Inventory}$$

- Inventory is defined as finished goods inventory of old stock from the previous month

- Installed capacity is the maximum possible production output quantity for the month

It is apparent from Eq. 4.5 that any extra capacity in excess of net sales is extra "*fat*" in the system since no income is generated on extra capacity unless put to an economic use. Therefore, the more inventory there is in the production system, the less the lean performance of the company is going to be. Equally, the more defects or rejects the manufacturing system produces the less the leanness level is going to be. This statement affirms the general lean principles of waste elimination. The leanness level is on a scale of 0 to 1, which makes it easy for analytical and comparative purposes.

The key therefore to achieving a good lean performance is the combination of quality control and JIT production, that is, 'manufacture only quality products that are pulled by the customer'. Just-in-time production minimises finished goods inventory, work-in-process inventory, and inventory from suppliers. JIT manufacturing strategy helps the firm to synchronise outputs to inputs defined as customer orders. This enhances fit factories ability to maintain a level of leanness proportional to market demand (sales) without having excess inventory or capacity carry-over. A synchronised just-in-time production system, therefore, helps to improve fitness by eliminating overproduction, unbalanced operations, waiting, and quality problems. Equation 4.2 can be re-written as:

$$LI = \frac{\text{Net Sales(\$)}}{\text{Installed Capacity(\$)+Inventory(\$)}} \qquad 4.6$$

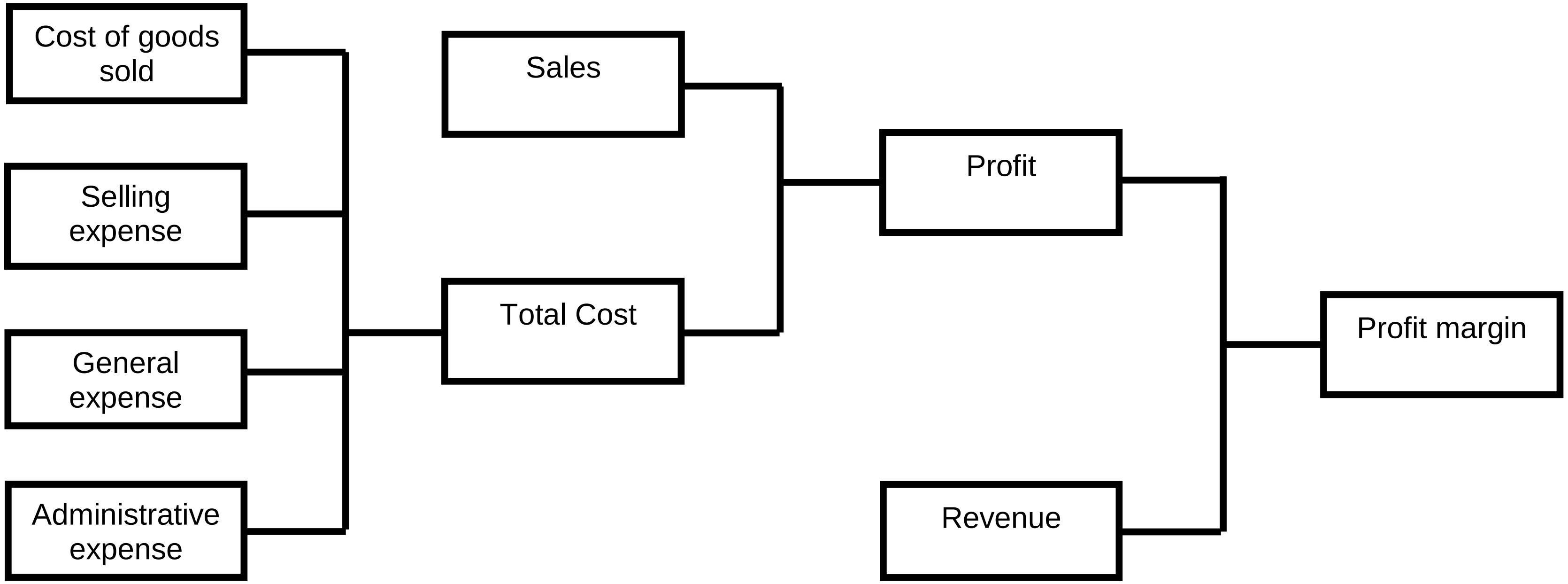
Where:

$$0.00 < \mathrm{LI}$$

Lean philosophy is all about eliminating waste, and Eq. 4.2 eliminates two critical types of waste, inventory and rejects/defects, commonly found in manufacturing. Each type of waste adds cost and delay to the products, eliminating them enhances the organisation's competitiveness and profitability, two critical contributors to a firm long-term fitness. In addition, it is pertinent to note that equations 4.2 and 4.6 make use of financial indicators of leanness i.e. sales, installed capacity, rejects, and inventory cost) in this regard the measure is considered as a single performance measure since it involves only financial variables.

4.3.2.1. Leanness Index Performance Measure: Sales

Under the fit manufacturing initiative, sales, also called pay-in-amount is defined as sales revenue which is determined by the price per unit product with the profit. Sales revenue and assets are two basic elements of profitability, each of these two elements have a number of components and the components making up sale revenue are depicted by the DuPont analysis chart, see figure 4.1 (Olhager, 1993).



Figire 4.1: A simplified DuPont sales analysis chart (adapted from Heard 1990)

Thor (1965) asserted that in many industries, increase in sales revenue usually coincides with increase in the quantity sold; similarly, a reduction in sales coincides with a contraction in quantity. Thor (1965) explained further that when sales revenue expands but quantity contracts, selling price received must be rising, otherwise, sales revenue would fall with the quantity. Thus, in sales expansion prices tend to rise more of the time than in quantity expansions. Equally, when sales revenue reduces but quantity increases, prices must be falling. This means, prices, tends to fall more of the time during reduction in sales period than during quantity reductions. Eq. 4.6 shows the relationship between sales revenue and quantity.

$$\text{Sales Revenue} = \text{Selling Price} * \text{Quantity Sold} \qquad 4.6$$

Eq. 4.7 shows that a company’s profitability is directly related to its sales revenue, and assets

$$\text{Profitability} = \frac{\text{Sales}-\text{Total Costs}}{\text{Total Assets}} \qquad 4.7$$

Total Costs = Cost of goods sold + Selling Expense + General Expense + Administrative Expense 4.8

Total Assets = Current Assets + Permanent Assets 4.9

Current Assets = Cash + Account Receivable + Inventories 5.0

Permanent Assets = Land & Building + Machinery & Equipment 5.1

However, Olhager (1993) studied four different contributing means on sales revenue, which also impact profitability. The author claimed that four different contributing means provide various forms of flexibility in the manufacturing system depending on the impact on sales, total cost and total assets. The four different contributing means are, namely:

i. Setup time reduction

ii. Capacity

iii. Multifunctional work force

iv. Modular product design

Under the fit manufacturing initiative, to get an optimal fitness level, it is argued that reduction of setup time to a minimum using a combination of reduced lot sizes, and maximised capacity utilisation rate through taking more orders or adding new products to the existing production system. Regarding capacity, Olhager (1993) argued that a certain level of excess capacity is useful in providing flexibility to the manufacturing system. This excess capacity is beneficial to product range flexibility, lead times reduction, delivery lead times reduction, and the ability to provide stability during demand variability. However, a strategic plan has to be in place to ensure that sales do benefit from the excess capacity either by accepting new business or taking higher customers' orders.

In the same vein, regarding multifunctional work force, under fit manufacturing system, it is argued that having in place a flexible, multi-skilled work force will help improve productivity which will invariably contributes to sales performance. A flexible workforce can especially be useful in getting the quality right first time, and in managing product range flexibility, and demand fluctuation. Equally, use of modular design may have positive impacts on sales at it provides product customisation options to customer and increases the chance to build-to-order rather than build-to-forecast Olhager (1993).

4.3.2.2. Leanness Index Performance Measure: Inventory

Slack (1997) defined inventory as what a company has purchased with the intention of selling, this include raw materials, work-in-process, and finished goods. Meng (2006) argued that inventory cost account for 30 percent of the total capital cost of manufacturing firms, hence, successful inventory management is often a symbol of competition victory and an indication of how well-run the organisation is. Notwithstanding, inventory can range from raw material, cash, finished goods, and so on. In this study, the term inventory refers to finished goods inventory. This type of inventory is important in a competitive market environment where importance is placed on price and delivery time. Consequently, in order to satisfy an organisation’s strategic competitive goal, it is very crucial to optimise inventory management. Eq. 5.2 presents a simple formula for calculating Ending Finished Goods Inventory, i.e.:

Ending Finished Goods Inventory =

(Beginning Finished Goods Inventory + Cost of Goods Manufactured)

- (Cost of Goods Sold) 5.2

Example 4.1

Suppose £50,000 of product A was estimated to be the beginning finished goods inventory. The cost of goods manufactured was given as £425,000. The cost of goods sold was given as £300,000. The solution below estimates the ending finished goods.

Solution

Beginning Finished Goods Inventory:	£50,000
Cost of Goods Manufactured:	£425,000
Cost of Goods Sold = £50,000 + £425,000 =	£475,000

Ending Finished Goods Inventory = £475,000 - £300,000 = **£175,000**

In general, the optimal limit of finished goods inventory is strongly related to the manufacturing strategies in place, Wanke and Zinn (2004) analysed three strategic level decisions:

i. Make-to-order (MTO) vs make-to-stock (MTS).
ii. Push vs pull inventory deployment
iii. Inventory centralisation vs decentralisation

Wanke and Zinn (2004) asserted that strategic decisions relating to inventory management are usually taken against the strategic choices of uncertainty, customer service and cost management. For instance, Dell Computer was reported as an example of a make-to-order and pull demand manufacturer, Dell only manufacture and distribute computers in response to a customer order. On the other hand, Hewlett-Packard, a direct competitor of Dell, manufactures new computers on the basis of a sale forecast. Li (1992) positioned that inventory holding strategy can be used as part of a manufacturing company's time-based competitive strategy for delivery reliability. However, the author also commented that, inventory holding strategy is not appropriate for competitive environment characterised by rapid changes due to the inflexibility in such strategy architecture and cost implications. Li (1992) further argued that usually, the optimal inventory limit will increase under certain conditions including higher demand rate, longer average production time, and lower holding cost.

Under the fit manufacturing initiative, to get an optimal fitness level, it is argued that finished goods inventory should remain as minimal as possible. Chhikara and Weiss, (1995) suggested that finished goods inventory can be minimised by increasing the production flexibility to allow for smaller batch sizes, together with frequent JIT deliveries. In addition, to minimise finished goods inventory, fit manufacturing encourages the integration of sales and marketing functions with the production system. This helps to sustain minimum finished goods inventory. Figure 4.2 is an illustration of the normative model of inventory carrying costs.

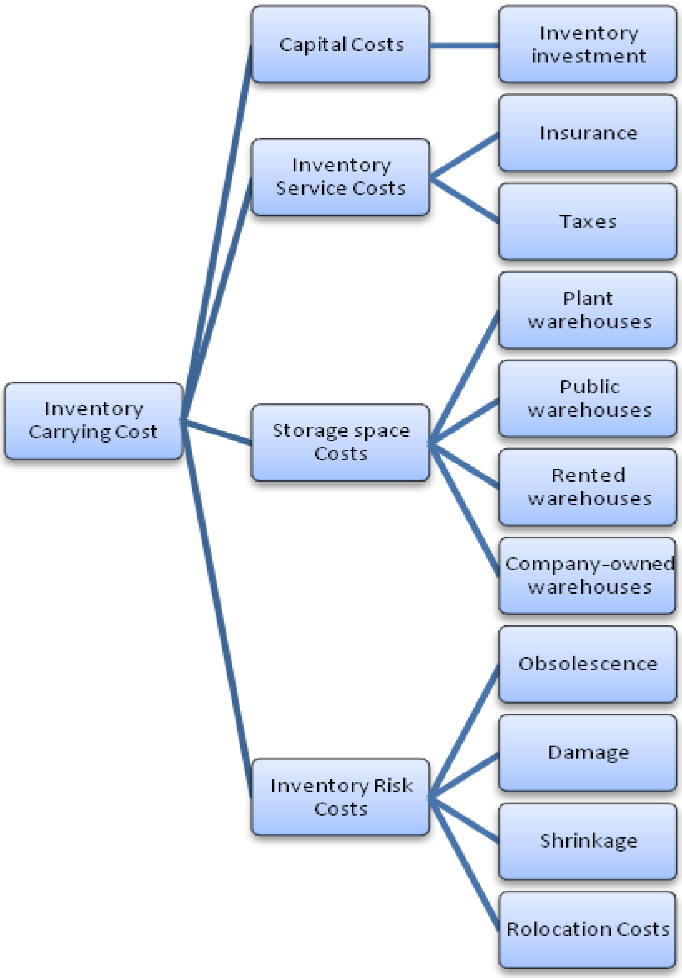


Figure 4.2: Normative model of inventory carrying cost (adapted from Meng, 2006)

4.3.2.3. Leanness Index Performance Measure: Rejects

At section 4.4.2 reject was defined as the current monthly figure of the combination of scraps produced during steady state production and sales returns due to defects i.e.

$$\text{Rejects} = \text{Scraps} + \text{Returns} \tag{5.3}$$

4.3.2.3.1. Scraps

Scraps or defects are visible production waste which can be directly estimated by the unit of quantity. A defect is defined as a non-conformance of a quality characteristic such as diameter, length, width to its specification. Defects or scraps are manifestation of out-of-control processes, incorrect schedules, information, and incorrect engineering designs. Other production wastes like excessive transportation, unnecessary motion, and waiting are considered as invisible production wastes that exist in the system. Ebrahim (2011) suggested that invisible waste can only be determined by differentiating value-adding activities from non-value-adding ones within the production time.

Hall (1989) claimed that organisations adopting JIT production report reduction in quality defects of 30 to 60 percent, reduced production times of 50 to 90 percent, and reduced capital expenditures of 25 to 30 percent. While the benefits of JIT production to achieving increased fitness level are quite obvious, Young (1992) reported that JIT implementation is often accompanied with increased pace of work, increased demands for production flexibility, employee discipline and concentration, and constant suggestions for improvement. The success of JIT has not been without its own criticism Ring (1995) reported that due to the flexibility demand of the production system and the accompanied increased work pace, employees may react negatively leading to some union leaders characterising the manufacturing strategy as “management by stress”.

Defect per unit (DPU) is the average number of defect per unit of a product. The ratio of defects to unit is a measure of quality.

Given:

D: total number of defects

U: total number of units

Formula:

$$DPU = \frac{Total\ Number\ of\ Defect}{Total\ Units} = \frac{D}{U} \qquad 5.4$$

Example 4.3

Ten pens were produced at a production facility and each has five quality characteristics (opportunities) where it can be defective. If a manufactured pen fails any of the five quality characteristics fails, then the product is considered defective. Given the table 4A at Appendix A, DPU can be estimated below:

Solution

Total number of opportunities: 10 * 5 = 50

I.e. total defects if each pen failed all the five quality characteristics

D (total number of defects in the 10 pens) = 3+1+4+2+1+4+2 = 17

The number of defective pens: 7

I.e. 7 out of 10 pens contained one or more defects qualifying them to be classed as defective

From the matrix

D = 17

U = 10 units (pens)

$$\text{DPU} = \frac{17}{10} = 1.7 \text{ defects per unit of manufactured pens}$$

4.3.2.3.2. Product Returns

A product can become defective during the design process, manufacturing process, distribution, or sale. Typically, product returns arriving at a manufacturer's facility are a combination of (Guide, et al., 2005):

i. Commercial returns whereby customer changed their mind or because the products are defective

ii. Channel returns due to overstocks or stock adjustment

iii. Demonstrative returns which includes ex-display or road show items

Once a commercial return is received at a manufacturer's facility, managers must then decide how to most profitably dispose of the product: reuse as-is, refurbish, salvage or recycle (Blackburn et al., 2004). Hambrick (1995) asserted that inspection, defects, scraps, rework, warranty cost, and other "cost of quality" accounted for 10 to 25 percent of product cost. Decreasing this cost is a major enhancement to achieving greater fitness level. However, effective and efficient management of product returns is an active research area that continues to engage researchers (Srivastava, 2006). Consequently, for the purpose of this work, product returns is directly estimated by the unit of quantity coming back into the manufacturing facility returns streams to be used as spare components, remanufactured for secondary market or scrapped. Figure 4.3 is an illustration of reversed supply chain for products returns.

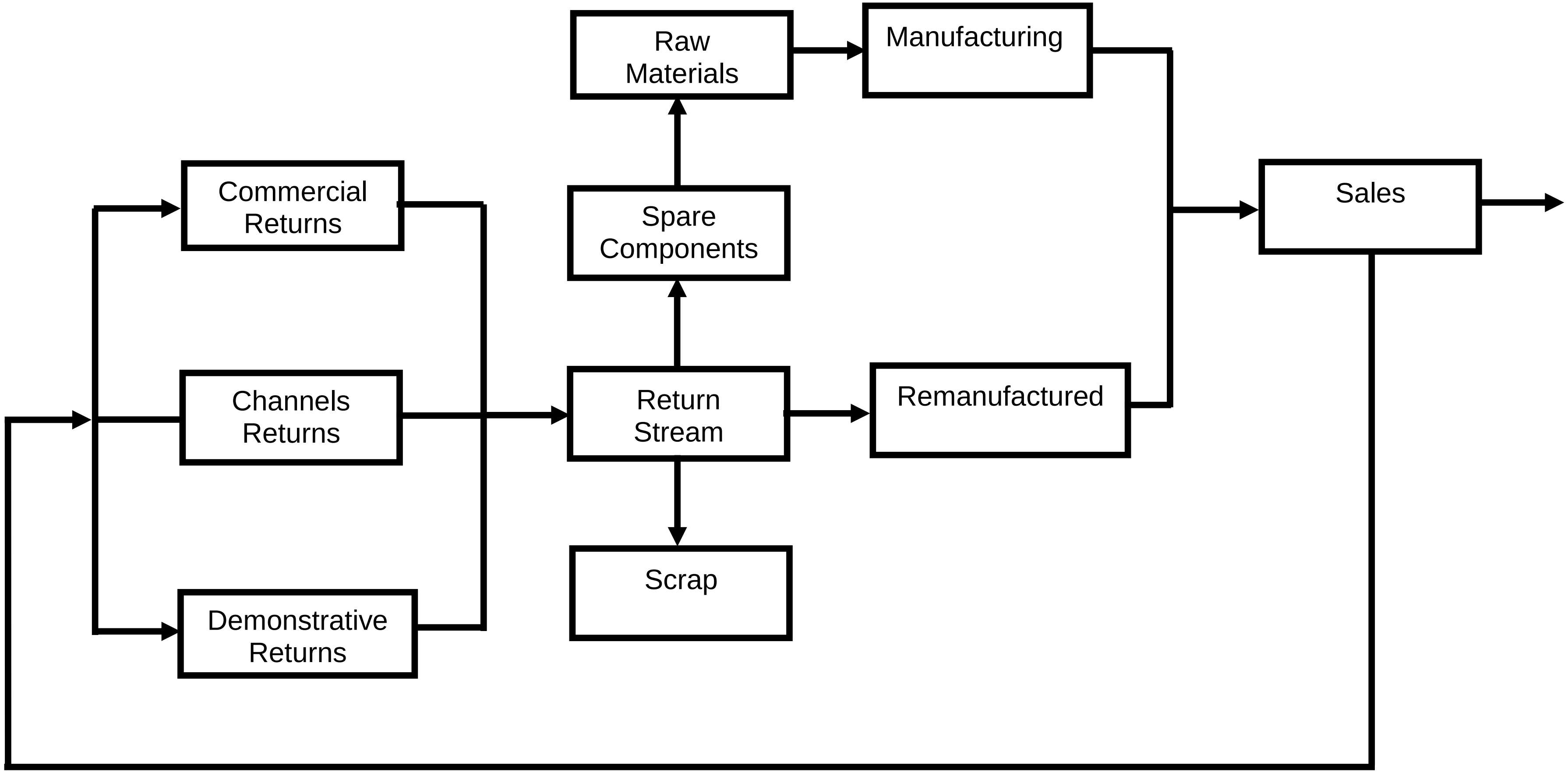


Figure 4.3: A reversed supply chain for products returns (adapted from Blackburn et al., 2004)

4.3.2.4. Leanness Index Performance Measure: Installed Capacity

Installed capacity refers a firm’s total installed equipment capacity that can be put to productive use. However, it is not unlikely to find manufacturing plants producing at below total installed capacity. Capacity utilisation is the percentage of the firm’s total possible production capacity that is actually being used. Equation 5.5 illustrates how capacity utilisation is calculated.

$$\text{Capacity Utilisation (\%)} = \frac{\text{Actual output per month (or per annum)x } 100\%}{\text{Maximum possible output per month (or per annum)}} \tag{5.5}$$

For the purpose of this study, installed capacity is defined as the maximum possible output per month. It therefore follows that a firm should be most efficient if it is running at 100 percent installed capacity. However, if a firm is running at total installed capacity, there are potential weaknesses (Perry, 1973; Higgins, 1996):

i. The probability of frequent occurrence of machine breakdowns increases because not enough time is available for routine maintenance

ii. The opportunities for taking in new or unexpected orders is diminished

iii. The pace of work is likely to be fast because there is no spare capacity in the system. This may lead to increased employees fatigue and labour turnover

iv. If the factory space becomes all used up and overcrowded, work may become less efficient and organised, increasing the opportunities for mistake

v. The probability of using overtime to fulfil orders may increase, thus increasing labour costs

Increasing capacity through additional investment usually offers the benefits of process optimisation, cycle time reduction, and increased plant availability. Extra investment in capacity will impact the batch sizes, helps reduces process variability, and increased the opportunities to better manage both planned and unplanned downtimes. In general, manufacturing firms tend to make use of sales trends in making investment decisions of increasing capacity. Most firms feel comfortable at a capacity utilisation of between 80 to 90 percent (Johns et al., 2003). This is because at this level of utilisation fixed costs per unit are relatively low and there are opportunities to meet new orders, carry out equipment maintenance, and less stress for employees.

In determining the leanness index, total capacity utilisation is considered because there is a cost associated with the capacity that is not been used at any time. However, the key to higher levels of leanness and fitness lie in the ability of the manufacturing firm to synchronise its activities with just-in-time production rather than "just-in-case". Therefore, efficient capacity utilisation is considered a key issue in determining not only the leanness level of the firm but also its long-term economic sustainability.

4.3.3. Leanness Index: An Illustrative Example

Suppose a firm's maximum possible output for the month is 1500units, and it has 60units of finished goods inventory at the beginning of the month. If the sales figure for the month is 1200units and rejects, combination of scraps and returns, is 60units, the firm's leanness index is as follows:

$$LI = \frac{\text{Sales} - \text{Rejects}}{\text{Installed Capacity} + \text{Inventory}} \qquad 5.6$$

Where:

$$0.00 < \text{LI}$$

$$LI = \frac{1200-60}{1500+50} = \frac{1140}{1550} \qquad 5.7$$

LI = **0.73**

A leanness index of 0.73 indicates that the firm needs to strive to achieve greater capacity utilisation and better inventory control management. At this level of leanness the quality rate is about 95 percent (100% -

(60/1200) x 100%)) = 95%), implying, an improvement to 100 percent quality would have increased the leanness index slightly to 0.77. Also, if the 50units inventory of finished goods were to be eliminated, a leanness index of 0.76 would be achieved. Whereas, if the capacity utilisation increased slightly by achieving greater sales of 1400units, the leanness index would increase to 0.86. Consequently, it is suggested that this firm improves on its marketing and sales strategy, and synchronise it production system closely with customer's demand in order to achieve greater capacity utilisation.

4.4. Fit Manufacturing: Agility Component

Many academics and practitioners alike conclude that agility is the ability to respond to changing customer demand (Christopher and Towill, 2000; Goldsby et al., 2006; Ramesh and Devadasan 2007). Dove (1994) succinctly defines AM as being proficient at change, enabling an organisation to do what it wants, when it wants. This view is reinforced by the earlier work of Kidd (1995) who claims agility gives rise to a competitive advantage, in that an agile company can respond rapidly to changes in the market environment. Jackson and Johansson (2003) view agility in terms of long term and short term change and state that agility differs from flexibility in that flexibility is the planned response to anticipated short term change, whereas, agility is the ability to deconstruct and reconfigure a system when required. However, there is no universally accepted way of measuring the agility of an enterprise (Kurian, 2006).

Ramesh and Devadasan (2007) identified twenty criteria for AM based on their literature study. However, these criteria did not apply to specific aspects of a manufacturing system. Apart from the twenty AM criteria identified by Ramesh and Devadasan, there are other criteria that have been used by other authors (Beck, 2012; Gunasekaran and Yusuf, 2002; Bunce and Gould, 1996; Gupta and Mittal, 1996) adaptable; virtual corporation; reconfiguration; long-term gains; responsiveness; deployment of technology; continuous improvement practised; strategic viewed; innovative culture; customer integrated process. However, Mason-Jones et al. (2000b) concluded that the key to be agile comprises flexibility and responsiveness, which are called the market winners of an agile supply chain against cost, which is called the market winner of leanness. The authors also stated that the market qualifiers for agility are quality, cost, and lead time, while quality, lead time and service levels are the market qualifiers of leanness.

On the other hand, Jackson and Johansson (2003) proposed a balanced response-to-change capability evaluation of agility across the four dimensions of cost, time, robustness, and scope; with scope being the principal difference between flexibility and agility. While Yusuf and Adeleye (2002) concluded that the main issues in AM are effectiveness, efficiency, flexibility, and responsiveness. This view is similar to the position held by Gould (1997) and James-Moore (1996) who asserted that developing agile organisations and facilities requires more flexibility and responsiveness. Figure 4.4 illustrates the conceptual model of agility based on the literature review showing six commonly cited performance measures. However, for the purpose of this study, and the need to minimise the complexity of the proposed agile index, it is assumed that the key criteria of agility are flexibility and responsiveness. More so, the leanness index already reflected two other dimensions of competitiveness namely cost and quality. Consequently, the agile fitness component is defined as the *ability to move quickly in respond to changing market demand by providing required product variety and production system flexibility*.

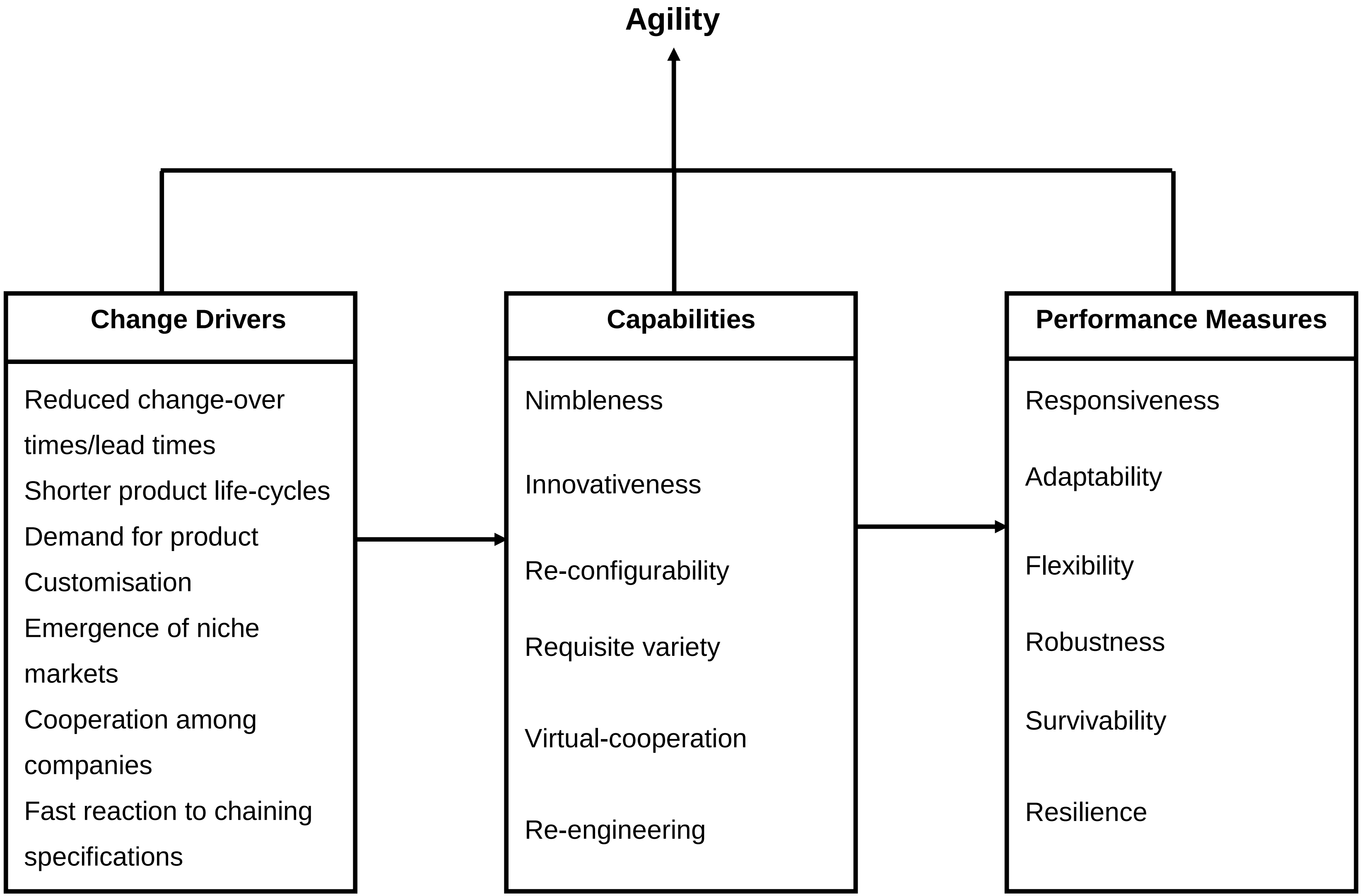


Figure 4.4: Conceptual model of change drivers, agile capabilities and performance measures

4.4.1. Agility Index Derivation

Considering the overall objective of this study, which is to develop a simple and easy to use fitness index, it is also argued that the agility index component shares the same requirements of simplicity, objectivity, integrative, universality and scalability defined at section 4.4.1. The agility index component of fit manufacturing assesses the ability of the production system to respond rapidly to changes in the market place.

It has been suggested that good agility requires a combination of speed, balance, power, and co-ordination (Ebrahim, 2011). Consequently, the speed is a good measure of agility (Ren et al., 2003). Agility Index (LI) is estimated using the definition of AM established at section 4.4. Having in mind that the main objective of AM is responsiveness given a level of flexibility. Thus, a company's level of agility can be determined by the average changeover in the factory relative to available product range (flexibility). This expression is written as:

$$AI = \frac{\text{Product Range Flexibility(n)}}{\text{Changeover time(k)}} \qquad 5.8$$

$$Agile\ Index = \frac{\mathrm{n}}{\mathrm{k}} \qquad 5.9$$

Where:

i. n < k: 0.00 < AI < 1.00

ii. n ≥ k: AI = 1.00

- *n* is the size of the product range (product size and volume size) offered by the manufacturing firm
- *k* is the average changeover time (minutes) for period under review

Following from equation (5.8):

***AI* < 1.00** means increasing production changeover time relative to product range flexibility

- ***AI* > 1.00** means increasing product range flexibility relative to production system changeover
- **AI = 1** means a state of "***perfect agility***"

This equation estimates agility in terms of product range per available changeover time. Here agility is defined as a function of the complexity of the production system to cope with internal and external uncertainties. The equation translates agile flexibility and responsiveness requirements into performance objectives of achieving optimal product range balance and changeover time. This equation measures agility fitness component requirement using information already being generated on the shop floor and therefore avoids the need to measure additional parameters. Measuring agility requirement this way does not need a lot of effort in practice.

This approach to measuring agility appears to use a key lean indicator, changeover time. The use of this lean indicator to develop an agile measurement tool should not be a surprise because lean is a pre-requisite for being agile. Proven quick change-over time incorporates systems and methods that help facilitate increased capacity utilisation, smaller batch sizes, lower inventory and reduced lead times, all key enablers of manufacturing agility (Shingo, 1985).

4.4.1.1. Agility Index Performance Measure: Flexibility

Slack (2005) argued that flexibility is a core competence that can be exploited in achieving long-term competitive advantage in any market context, more so, given that today's market condition can be described as turbulent, fast moving, and competitive, flexibility allows a firm to increase its market positioning. However, according to researchers, the nature of flexibility as a concept is ambiguous; in addition, there is no universally agreed definition of the concept (Slack, 2005; De Toni and Tonicha, 1998; Sethi and Sethi, 1990; Gutpa and Goyal, 1989). Similarly, Slack (2005), pointed out that there are contending perspectives on how the overall strategic role of flexibility should be assessed either as flexibility of alternative process technologies, or human resources flexibility, or as infrastructural processes flexibility. However, a general view on flexibility does exist among researchers. This viewpoint sees flexibility as a prerequisite to effective response to changing market needs (Gerwin, 1993; Bayus and Putsis, 1999; Barnes-Schuster et al., 2002).

A number of flexibility classifications can be found in the literature, most are closely related to the four types of flexibility that can be found at the total manufacturing system level identified by Slack (1987), namely:

i. New product introduction flexibility

ii. Product mix flexibility

iii. Volume flexibility

iv. Delivery flexibility

Within the context of this work, *flexibility is defined as ability to cope with uncertainties in product range (the combination of product mix flexibility and volume flexibility) given a level of response without comprising on acceptable quality levels.* This statement defines flexibility in two dimensions - range flexibility and response flexibility. This is consistent with the observation made by Slack (2005). Finally, a robust system of production equipment, product design, work organisation, and information technology (Gerwin, 1993) needs to be available to handle variable product mix and continuous introduction of new products (Beck, 2012; Hasan, et al., 2012).

4.4.1.2 Agility Index Performance Measure: Responsiveness

Measurement of agility gives an enterprise an indication of its competitiveness and readiness for unpredictable changes in the market. Hence, measuring agility helps an enterprise to evaluate its agility performance component of fitness, and to also identify areas within the business which may require improvements. It has been argued that lean is a pre-requisite for being agile, and that going from lean to agility is a transition (Erande and Verma, 2008). Given this background, the performance objective of achieving responsiveness is evaluated using change-over times, a key lean indicator. Change-over times could be in terms of few minutes as well as several weeks depending on the nature of the end product.

As previously observed, proven quick change-over time incorporates systems and methods that help facilitate increased capacity utilisation, smaller batch sizes, and reduced lead times. Under lean manufacturing, quick change-over time is called Single Minute Exchange of Die (SMED). SMED is a lean production method that emphasis the target of achieving less that 10 minutes changeover of converting a manufacturing process from running the current product to running the next product (Shingo, 1985).

4.4.2. Agility Index: An Illustrative Example

Suppose a firm has a product range of three varieties, and currently achieving average change-over times of 10 minutes. The firm's agility index is estimated as follows

$$AI = \frac{\text{Product range flexibility}}{\text{Change}-\text{over time}} \qquad 6.0$$

Where:

$$0.00 < \text{AI}$$

$$AI = \frac{3}{10} \qquad 6.1$$

$$AI = 0.3 \qquad 6.2$$

An agility index of 0.3 indicates the equipment flexibility of the production system; i.e. the efficiency level of the production system to deal with mixed parts or allow variation in parts assembly given current average change-over time. The agility index serves as an indicator of internal process performance and can be used to drive improvement effort in the reduction of change-over time, improved workforce productivity, greater machine efficiency, and impact assessment of new product introduction.

For the illustrative example, agility index of 0.3 implies that given the current level of uncertainties, the manufacturing system has 30 percent product range flexibility and 70 percent responsiveness. This level of agility might be good for certain market conditions where the requirement for high product customisation is limited and emphasis is on responsiveness, that is, faster change-over time. However, if the market dynamics were to change resulting in greater demand for product customisation, the firm will need to work to improve the product offerings (range) and improve product flow through shorter change-over times.
Achieving shorter change-over times might require additional investment in production equipment, and associated information technology, two key flexibility enablers. It is also possible that a reconfiguration or modification of the controlled settings of the production equipment is all that is required to improve product change-over time.

In general, shorter change-over times help reduces overproduction waste caused by the traditional scheduling systems, inventory waste, unnecessary waiting, labour cost and yield losses, all major waste under LM. This suggest there is a positive relationship between leanness and agility, as one performance measure increases the other should also benefit from the knock-on effects from the improvement activities Within the context of fit manufacturing, the key therefore to achieving higher levels of agility is to increase product range flexibility capability, reduce average change-over times, and improve production flow. Figure 4.5 illustrates the ideal relationship between product range flexibility and responsiveness.

4.5. Fit Manufacturing: Economic Sustainability Component

Economic sustainability is defined as the ability of a firm to be accountable, responsible, viable and profitable for now and for the future. It is the ability of a firm to survive now and for the long-term while earning sustainable profit. An economically sustainable firm is efficient and capable of guarantying not only short-term profit but also improved prospect of long-term survival. Found and Rich (2006) defines the concept as the ability to extract, in some time period, revenues that outweigh the costs of operating the firm and thereby securing the future of the firm. Doane and MacGillivray (2001) define the economic sustainability as the business of staying in business. Dyllick and Hockerts (2002) defined the economic sustainability as meeting the needs of a firm’s direct and indirect stakeholders (such as shareholders, employees, clients, pressure groups, communities etc) without compromising its ability to meet the needs of future stakeholders as well. Pasmore (1988)

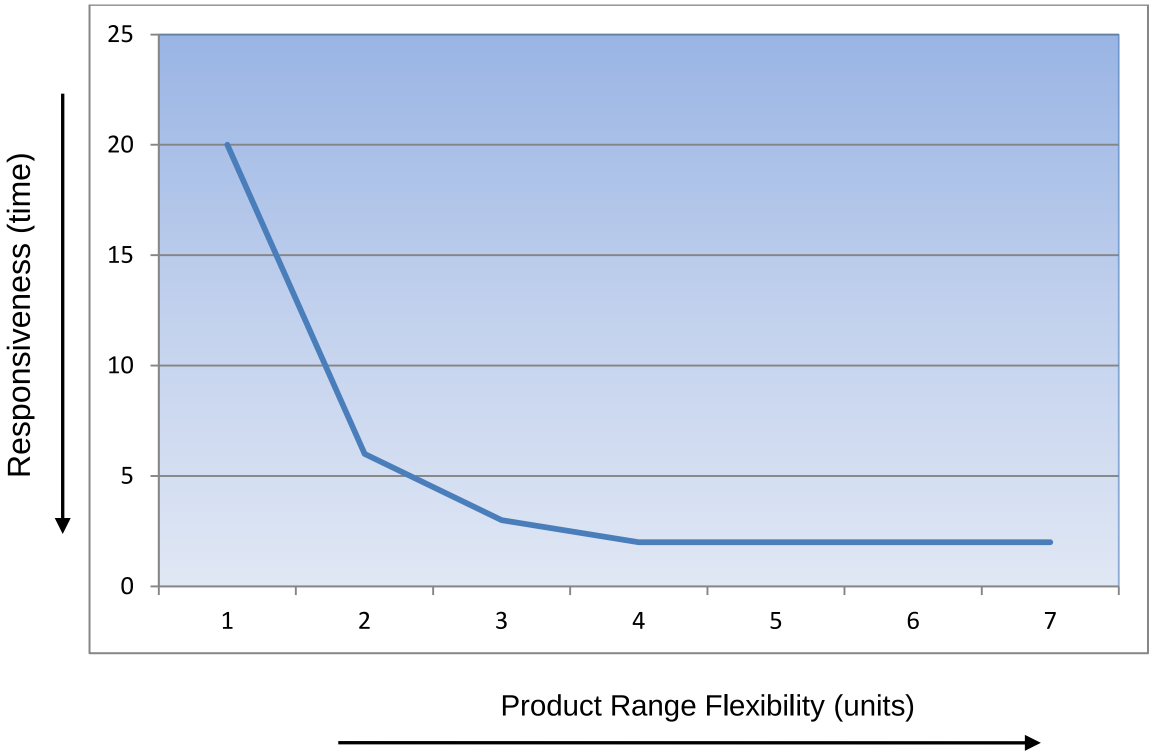


Figure 4.5: Ideal Relationship between product range flexibility and responsiveness

suggested that **“**economic sustainability is based upon the rudimentary input-process-output cycle and the flow of revenues and the absorption of costs within a business**”**. Through its intrinsic nature, economic sustainability implies longer planning horizons and formulation of business policies that make the business to be proactive rather than reactive (Welford, 1995).

Essentially, economic sustainability is about the economics of keeping the business running as a profitable enterprise for now and for the future. It also involves paying attention to social and environmental issues that may be barriers to long-term economic future (Doane and MacGillivray, 2001). The concept encourages business managers to formulate and pursue not only short-term efficiency and profitability goals but also long-term survival goals such as investment in right capabilities and the acquisition of survival skills. While the main goal of economic sustainability can be defined as long-term survival there are other goals incidental to business perpetuity such as value creation and growth.

The extents to which the goals of economic sustainability are met, however, depend on a number of factors including the willingness of the management to purse long-term goals at the expense of short-termism (Moore, 2000) and to make stakeholders buy-in to the vision. The danger of focus on meeting short-term operational goals is that management can be lulled into a false sense of security by taking present operating conditions for granted. They make no preparedness attempts for changes in the business environment. Survival situations often develop rapidly, and when such sudden events occur like the credit crunch of 2007/2008 ill-suited firms; even ones with best strategies, resources and intensions; are caught napping and fall victim easily (Pham et al., 2011). On the other hand, having in place a fit system that implements the advance warning mechanism (AWM) proposed in this study, would have helped mitigate against the rapid declined of enterprise. The advance warning mechanism would perhaps have helped project the driving forces of the crises and the potential impacts on the long-term fitness of the business.

4.5.1. Economic Sustainability Index Derivation

Against the competing views and perspectives on economic sustainability expressed in section 4.8 above, the followings are extracted as the overriding features that best describe the intricate nature of the phenomena. For the purpose of fit manufacturing, it is proposed that economic sustainability can be evaluated along the following financials and non-financial parameters (Found and Rich 2006; Moore, 2000; Welford, 1995; Pasmore 1988):

i. **Efficiency of profitability**. This represents the ability of a firm to extract profit .i.e. revenues that outweigh the costs of operating. For the purpose of this work, this capability is determined as the ratio of total paid-out to total paid-in for a given period of time. It measures the overall efficiency of the firm to generate revenues in excess of operating costs.

ii. **Efficiency of conversion or growth efficiency**. This represents ability of the firm to successfully complete input-process-output cycle required to aid the flow of revenues and the absorption of costs within the business. In this study, this property quantifies the rate at which a firm earns excess returns on new investments. Growth is a long-term survival condition and is an important dimension of a far regardless of its sizes. A growing firm may be able to increase its market share, introduce new products, new processes and organisational techniques to enhance its competitiveness to survive. In financial accounting this is call revenue growth rate; the ratio is used to determine how far into the future a company's cash flows can be projected. However, forecasting a company's revenue involves making assumptions about it future cash flows (Investopedia, 2012). Due to the limitation of available data on case study companies' revenue growth rate, this indicator is treated as a constant.

iii. **Efficiency in survival**. This represents the ability of a firm to guarantee not only short-term profit but also improved prospect of long-term survival. In this study, this property qualifies the relative efficiency of survival times (time to death) of a firm given survival data for the industry (i.e. 'group experience') for a fixed period of time (Willian, 1983). Forecasting a company's probability of survival involves making a number of difficult assumptions which would be outside the scope of this work. Due to the limitation of available data on case study companies' the efficiency in survival is kept as a constant.

iv. **Management effectiveness.** This represents the ability of the firm to formulate business policies and implement changes that make the business to be proactive rather than reactive. Richard and Johnson (2001) using the resource-based view of the firm, argued that strategic human resources management (SHRM) effectiveness affects organisational level outcomes. The authors claimed that management effectiveness significantly reduces employee turnover and increases overall market performance assessment. However, measuring management effectiveness is a subjective concept because effectiveness is a non-quantifiable concept that tends to be evaluated using subjective criteria such as reliability, maintainability, and availability (Al-Darrab, 2000).

v. **Utilisation efficiency.** This term represents the ability of the firm to compete through efficient utilisation of the factors of production. This capability quantifies the productivity of the firm at utilising available resources to generate sales/revenue. Al-Darrab, (2000) argued that productivity efficiency is more than reducing the staffing levels but also encompasses doing more with same resources, doing less with greater reduction in resources, and doing more with marginal increased in the resource consumed. Therefore, for a manufacturing firm to be sustainable and successful for long-term, the firm's productive ability is an important factor for consideration.

Using the above analysis, it follows that economic sustainability concerns the concepts of efficiency and effectiveness (Found and Rich, 2006) in the management of an enterprise. Thus, equation 6.3 is proposed as a measure of economic sustainability index:

Economic Sustainability Index (ESI) =
(Profitability Efficiency) x (Growth Efficiency) x (Survival Efficiency)
x (Management Effectiveness) x (Utilisation Efficiency) 6.3

i.e. $$ESI = (PE) \times (GE) \times (SE) \times (ME) \times (UE)$$

Where:

- **0 < ESI**

However, for the purpose of this study, in order to evaluate the economic sustainability performance of a firm emphasis is placed on efficiency factors. This is because, in general, efficiency is a measurable concept and can be assigned a numerical value. On the other hand, effectiveness is a subjective concept. In addition, given the scope of this work and against the overriding requirement to develop a simple, easy to use economic sustainability index (ESI), Eq. 6.3 is re-written as 6.4 keeping efficiency in survival as a constant and eliminating the non-quantifiable input Management Effectiveness:

$$ESI = (PE) \times (GE) \times (SE) \times (UE) \times K \qquad 6.4$$

Where:

- Constant *K* = 1; Eq. 6.4 becomes:

$$ESI = (PE) \times (GE) \times (SE) \times (UE) \qquad 6.5$$

Similarly, if growth efficiency and survival efficiency are removed from the equation to reduce complexity, more so, there is paucity of data on these two factors from the case study companies. It follows that Eq. 6.5 can be re-written as:

$$\mathbf{ESI = (PE) \times (UE)} \qquad 6.6$$

i.e. ESI = (Profitability Efficiency) x (Utilisation Efficiency)

Within fit manufacturing initiative, profitability efficiency is defined as the ratio of total paid-in (total revenue generated as output from the production process) to paid-out (total cost input into the production process), i.e.:

$$\text{Profitability Efficiency(PE)} = \frac{Total\ Paid{-}in(\$)}{Total\ Paid{-}out\ (\$)} \qquad 6.7$$

Where:

- Total Paid-in ≥ Total Paid-out
- Total Paid-in is the Sales Revenue for the month
- Total Paid-out is the total cost of production input quantity amount for the month
- PE < 1.00 indicates less than optimal profitability factor
- PE > 1.00 indicate greater profitability factor than expected

Similarly, utilisation efficiency is proposed as the ratio of sales to maximum available production capacity, i.e.

$$.Utilisation\ Efficiency\ (UE) =$$

$$\frac{Actual\ output\ per\ month\ (or\ per\ annum)}{\text{Maximum possible output per month (or per annum)}} \qquad 6.8$$

Where:

- Actual Output Quantity ≤ Maximum Possible Output Quantity
- Actual Output Quantity is the actual production output quantity for the month represented as the sales figure
- Maximum possible output per month (or per annum) is the combination of the Inventory at the beginning of the period and Installed capacity
- **0 < UE ≤ 1**

From Eq. 6.6 Economic Sustainability Index (ESI) is determined as:

$$ESI = \left(\frac{Total\ Paid{-}in(\$)}{Total\ Paid{-}out\ (\$)}\ X\ \frac{Actual\ output\ per\ monthh\ (or\ per\ annum)}{\text{Maximum possible output per month (or per annum)}}\right) \qquad 6.9$$

Where:

- ESI <1.00 indicates less than optimal sustainability factor
- ESI > 1.00 indicate greater sustainability factor

Note:

If Total Paid-in = 0

Or Total Paid-in < Total Paid-out (for a loss recording period)

Or Actual Output Quantity = 0

Then:

Economic Sustainability Index (ESI) = -1

A negative sustainability score indicates a loss recording and/or a zero capacity utilisation month. This gives vital information to managers of the manufacturing plant to take urgent steps to address issues regarding production costs, sales performance and capacity utilisation.

4.5.1.1. Economic Sustainability Index Performance Measures: Paid-Out and Paid-In

Profit margin is frequently used as an accounting measure to evaluate the financial health of a firm or industry. In general, it is defined as the ratio of profit earned to total sales revenue (or costs) over some defined period of time. Profit margin is also used to provide an indication of efficiency level at which a company recovers not only its costs of production (direct costs of the product, operating expenses, and costs of debt) but also compensations it receives (Bragg, 1999; Anthony and Pearlman, 1999). However, in this study, input and output amounts ratio have been used to help determine the efficiency of the company at recovering costs of production while earning a profit. The input amount represents by the sources of all pay-out amount (both direct and indirect costs). Conversely, the output amount represents the pay-in amount from sales revenue. Thus, for a sustainable competitiveness, it is important that a manufacturing firm is able to minimise it pay-out amount while maximising the pay-in amount.

A. Total Paid-Out Amount

This refers to the amount paid-out in respect of schedule production input over a period of time for instance a week, a month or a quarter. Consequently, the total paid-out amount is determined by the scheduled production input quantity of a product multiplied by the current average cost of unit product. For example, suppose the monthly production schedule quantity for Product A is 10,000 units, and Product B is 5,000units. A unit of Product A cost £2.00 to produce, and for Product B unit cost is £3.00. Therefore, the total paid-out amount for the scheduled input quantity is determined as shown below in Eq. 7.0:

Total Paid-Out Amount = Schedule Quantity x Average cost per unit product (7.0)

= (10,000 x £2.00) + (5,000 x £3.00)

= £20,000 + £15,000

= £35,000

Production paid-out amount is recovered through sales revenue. Sale revenue generates cash flow for the business, an important requirement for the financial health, long-term survival and economic sustainability of the business.

B. Total Paid-In Amount

Unlike total-paid out amount, total paid-in amount represents the sale revenue the business attracts as payback for the total product cost incurred. However, paid-in amount can be with or without profit (loss). Usually, profit is determined by the difference between paid-in amount and paid-out amount. The larger the paid-in amount over paid-out amount, the higher the level of profit level accrued. Consequently, the level of profitability is a measure of the financial health of the firm, its economic sustainability, and a good indication of its fitness level. It also provides an indication of the competitive success of the business, however, while the objective is to increase the profitability level of the firm it is also important to relate profitability to its source so as to identify products with good yields and those that might require improvement effort. Generally, profitability relies not only on sales and marketing strategies, but also on the production efficiency (Ebrahim, 2011).

Using the example above, suppose the monthly production schedule quantity for Product A is 10,000 units, and Product B is 5,000units. A unit of Product A cost £2.00 to produce, and for Product B unit cost is £3.00. Furthermore, suppose a unit of Product A sells for £2.30 and 9,500 units were sold in total. Conversely, a unit of Product B sells for £3.35 and 4,900units were sold in total. Therefore, the total paid-in amount for the scheduled input quantity is determined as shown below in Eq. 7.1

Total Paid-in Amount

= (Quantity Sold x Selling price) 7.1

= (9,500 x £2.30) + (4,900 x £3.35)

= £21850 + £16,415

= £38,265

Profitability = (Total Paid-in Amount) – (Total Paid-Out Amount) 7.2

Where:

Total Paid-Out Amount = £35,000

Profitability = £38,265 - £35,000

= £3,265

Finally, economic sustainability is quite a difficult concept to define more so, the concept remains relatively under-researched in literatures. Though there are a lot of materials on the broader concept of sustainability, however, the concept appears largely restricted to environmental issues. Furthermore, evidences of broader definition of sustainability including economics of sustainability can be found in literature, however, most of these material are focused on finite resources in long-term ecological or physical feasibility of continued economic expansions.

4.5.2. Economic Sustainability Index (ESI) Classification

From Eq. 6.3:

$$ESI = (PE) \times (GE) \times (SE) \times (ME) \times (UE)$$

Subsequently, this study introduces three types of sustainability zones based on ESI performance, each of which indicate the state of health and well-being of the enterprise. The zones are: Un-sustainable Zone (Low ESI), Sustainable Zone (Medium ESI), and Fit Zone (High ESI). The zones are utilised to indicate a firm’s overall output against sustainability measure, and helps highlight to management the need to either take proactive steps in policy formulation so as to sustain current performance, or make changes to improve the enterprise long-term profitability and sustainability.

Coloured zones are used to represent each of the three ESI classifications. Here the standard colours of traffic lights are adopted to express similar message. Figure 4.6 illustrates the three coloured zones classification adopted in this study

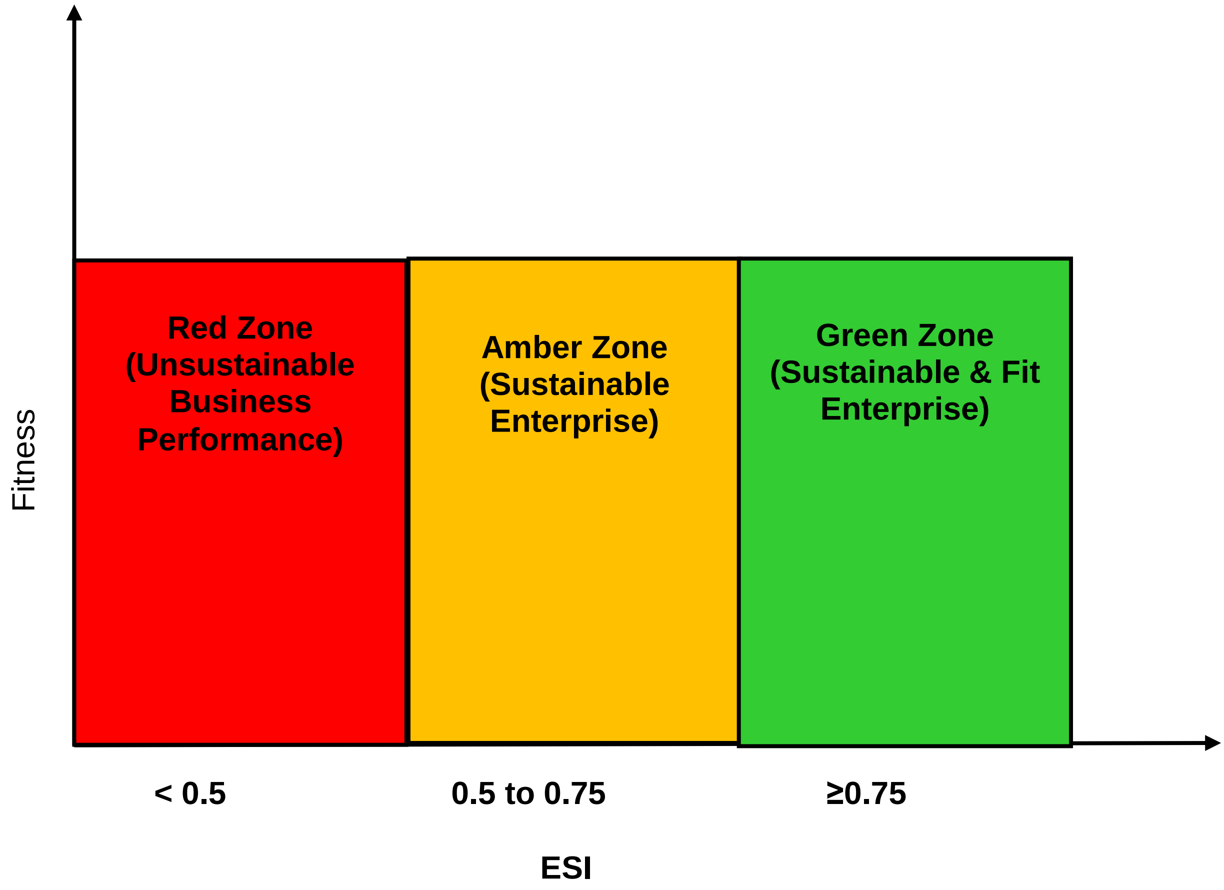


Figure 4.6: Classification of ESI Performance Outputs

- Red (Low ESI): means the organisation current performance is not sufficient to guarantee long-term sustainability unless new direction is sought and changes made to the business efficiency performance. The zone emphasises the need for a drastic improvement in all areas of business including but not limited to profitability efficiency, ability to attract and develop new growth opportunities, production operations management, and sales and marketing strategies. At this zone level, the enterprise runs the risk of going out of business if urgent actions are not taken.

- Amber (Medium ESI): this means the organisation current performance is sustainable; however, if the business is lulled into a false sense of security it runs the danger of becoming unsustainable. On the other hand, if the business was to improve its current sustainability performance it could become fit, a higher level of enterprise well-being, profitability and long-term sustainability.

- Fit Zone (High ESI): indicates the enterprise current performance is sustainable and fit for long-term success. However, more still need to be done to make the current efficiency performance outputs endurable and long-term success sustainable.

4.5.3. Economic Sustainability Index: An Illustrative Example

Suppose a firm's maximum possible output for the month is 15,000units, and it has 60units of finished goods inventory at the beginning of the month. However, 10,000units of Product A were produced at a unit cost of £2.00. Furthermore, suppose a unit of Product A sells for £2.30 and 9,500 units were sold in total, and rejects, combination of scraps and returns, is 60units, the firm's sustainability index can be estimated as follows

Solution

$$\text{ESI} =$$

$$\left(\frac{\text{Total Paid}-\text{in}(\$)}{\text{Total Paid}-\text{out}\ (\$)}\ \text{X}\ \frac{\text{Actual output per monthh (or per annum)}}{\text{Maximum possible output per month (or per annum)}}\right)$$

Total Paid-in amount = (Quantity Sold x Selling price)

= (9,500 x £2.30)

= £21,850

Total Paid-Out Amount = (Schedule Quantity x Average cost per unit product)

= (10,000 x £2.00)

= £20,000

$$\text{ESI} = \left(\frac{21{,}850}{20{,}000} \text{ x } \frac{10{,}000}{(15{,}000+60)}\right) \qquad 7.3$$

$$\text{ESI} = 1.09 * 0.66$$

$$\mathbf{ESI = 0.72} \qquad 7.4$$

From Eq. 7.4, an ESI of 0.72 implies the business current operation is sustainable; however, for the firm's performance to improve to the level of long-term fitness, the business will need to work more on improving capacity utilisation through greater synchronisation of demand-production management (JIT production), and sales and marketing strategies.

4.6. Summary

In this chapter, the three constituent components of fit index, namely lean index, agile index, and economic sustainability index, were presented. Each of the index attempts to measure efficiency of the different dimension of the production system and suggests ways of improvement. For example, the lean index assesses the production system's efficiency at producing quality goods, eliminate waste, and grow the revenue. The agility index evaluates the efficiency of the production system flexibility (product range) against responsiveness to unpredictable changes in the market place, while, the economic sustainability index evaluates the firm’s performance against five dimensions of sustainable performance. The chapter also discussed illustrative examples for each index, and qualifying criteria of against which the indexes were developed, namely: simplicity, objectivity, integrative, universality, and scalability. In the next chapter, Chapter 5, a fitness index is proposed, and attempt is made to optimise the fit model.

Chapter 5

Results and Discussion

"It is important that an aim never be defined in terms of activity or methods. It must always relate directly to how life is better for everyone. .. . The aim of the system must be clear to everyone in the system. The aim must include plans for the future. The aim is a value judgment". Dr. W. Edwards Deming

5.1. Introduction

In Chapter 3, a framework for fit manufacturing was proposed. Fit manufacturing was described as a total manufacturing concept founded largely on the theme of integration, by linking the manufacturing efficiencies achieved through lean and agile manufacturing with the overall business strategy of sustainability. Chapter 4 discussed the various components of fit index, namely leanness index, agility index, and economic sustainability index. Consequently, this chapter presents a fit index as the output of a manufacturing company against leanness, agile and sustainability performance enablers. Using case study data, an attempt is made to validate the research hypothesis which states that a over a period of time fitness outcome takes the shape of an "S Curve" when depicted graphically. Furthermore, the chapter discusses attempts to optimise the fit model using uni-optimisation approach, bi-optimisation, and multi-optimisation. Results from these optimisation approaches are compared for further analysis.

5.2. Case Studies and Data Collection

This study made use of archival data collected from survey research covering six SME manufacturing companies in Malaysia. Sample production and marketing data were collected during a five-year period from 2005 to 2009 by Ebrahim (2011) using three different approaches:

(i) Archival data

(ii) Interviews with top and middle management, and operators

(iii) Observations of manufacturing process, production work flow at the case study companies shop floors.

It is important to mention that in the initial survey conducted in 2005, 27 manufacturing companies in various industrial sectors and of different size in the Melaka region of Malaysia were contacted, unfortunately; only six companies agreed to participate in the study.

5.3. Review of Research Data

Archival survey data were used for the study; this has both disadvantages and advantages. Generally, archival research uses publicly available records and documents as source of data; the research is seen as being one step away from actual observation. On the other hand, survey research uses people’s reports of what they have done or will do as the source of data; thus the data reflects indirect observation rather than direct observation. However, both methods greatly increase the range of questions that can be investigated (Rutgers-Camden, 2004). In addition, Jones (2010) argued that archival data may be thought of as information previously collected by others; therefore, the focus should be on how to use the collected information for systemic study to answer questions. The author, Jones (2010), pointed out that use of archival data is prevalent across disciplines including psychology, economics and astronomy.

5.3.1. Advantages of using Archival Data

From the perspective of using archival survey data available from the case study companies, it can be said that the data are relevant as the information contained represent a good sample for this study. The collected data has the information about the nature of production fitness and this represents a substantial savings in time, efforts and money required to gather new set of comprehensive data for analysis.

Furthermore, the fact that the data have already been utilised for a similar study, also means that there is minimal concerns about institutional review. More so, the archival data were collected using survey research which provides a good foundation for generalising results from this study.
In addition, Rutgers-Camden (2004), pointed out that archival data has empirical advantages because such data allows investigations of questions that would otherwise be impossible or difficult to study. For

example, comparative studies of how the societies have changed over periods of historical time are not possible without archival data.

5.3.2 Disadvantages of using Archival Data

A disadvantage of using the archival data is that the data collected did not include some information such as monthly figures of capacity utilisation in the six case study companies. More so, the data were collected based on the operational performance at case studies companies during the period of 2005 to 2009, it is very likely that the case studies companies have undergone changes and the archival data no longer reflects current state of operational performance. In addition, there is the potential weakness that data collected during the survey research contains a number of assumptions which were then used to re-constructed missing data. For instance, Ebrahim (2011) reported that during the study of the case study companies, some data were not available, such as production input and output quantities, these unavailable data were constructed using other relevant data. Other reported assumptions in the original survey research conducted by Ebrahim (2011) included:

(i) For the wrong delivery products, products returned to the manufacturing facility, were assumed to be added to the inventory

(ii) For returned products which occur because of the quality problems, the cost of the returned product was assumed to be similar to the current cost per unit product in a particular month.

(iii) For production scraps and defectives, the costs were assumed to be based on the current cost per unit product in a particular month

(iv) Raw material and WIP inventories were ignored and assumed as part of a continuous product making process

(v) Fractional lot sizes were rounded up with the assumption that there will not be significant loss of optimality

(vi) Absence of manpower was assumed negligible so that the production operations were only interrupted by machine breakdowns and unpaid break times.

(vii) The maximum possible production input quantity was assumed to have a higher rate of machine downtimes in the particular month.

(viii) The FIFO queuing priority was assumed to have been applied for the production facilities with limited capacity

Samples of the original questionnaire used to collect general information about the case study companies are shown in Appendix B-1, while

Appendix B-2 contains summary of the case study companies' characteristics.

5.4. Characteristics of the Case Study Companies

The six case study companies operate in four different industrial sectors as highlighted in Table 5.1 below. In addition, the table shows that five of the case study companies can be classified as manufacturers of consumer products, with one case study company classified as manufacturer of semi-finished products. It is possible that product classification and differences in industrial sector could influence fitness outcome of the case study companies, because, a company performance is related to its industrial sector and type of goods it manufacture. This dictates the characteristics of products demand profile (sales), a key indicator for assessing OPFI.

Case Study Company	Industry Classification	Product Classification
Case Study Company 1	Rubber and Plastic Products Industry: Plastic plate, sheets, tubes and profiles	Semi-finished Goods Manufacturer
Case Study Company 2	Chemical Industry: Fertiliser manufacturer	Consumer Goods Manufacturer
Case Study Company 3	Food Products Industry: Processing and preserving of fish, crustaceans and molluscs	Consumer Goods Manufacturer
Case Study Company 4	Chemical Industry: Soap and detergents, cleaning & polishing preparation	Consumer Goods Manufacturer
Case Study Company 5	Beverages Industry	Consumer Goods Manufacturer
Case Study Company 6	Beverages Industry	Consumer Goods Manufacturer

Table 5.1: Classification of the case study companies

In addition to industry and production classification, it is possible to classify the case study companies as to their market status and market position. Market status can be divided into two categories namely national market and international market. Companies who are players in international market generally have global network of expertise, technological know-how, diversified customers based, and shared production costs. Thus market status of a company could influence its fitness performance. There is only one company out of the six case study companies that is involved in international market.

Similarly, a company's market position can also influence its fitness performance. Companies can be classified according to their individual market position either as a market leader or a market follower. Other variables that can also influence a company's fitness performance include among others the product distribution method, the company size, the number of operating days, and the type of manufacturing process.

Product distribution method contributes to the generation of demand quantity and could influence a company's fitness performance score. Two common methods of product distribution used by manufacturers to distribute their products are Direct-to-consumer, and distributor method of using third parties to get the product to the end users. The case study companies include two companies that use the direct-to-consumer method of distribution, and four companies that make use of distributor method.

Regarding the variable company size, all the six case study companies can be classified as micro-SMEs of between 1 to 10 employees with approximately 2 million annual turnover or approximately 2 million annual balance sheet (European Commission, 2005). This implies there is no large company in the study which could distort the final results and influence fitness scores. More so, using a sample of micro-SMEs for the study is not unusual because micro-SMEs play a crucial role in the economy; they are a major source of entrepreneurial skills, innovation, and employment (Medal-Bartual, et al., 2012).

The standard production operating days including the number of holidays in the year and overtime on offer could influence production capacity utilisation and distort the sample data. More so, overtime has the effect of increasing the cost of production; all these taken together could influence fitness scores and conclusions.

Similarly, the type of production process used by companies could influence fitness performance analysis and conclusions. All the case study companies are into batch processing production. However, batch processing production can be classified into three categories, namely: single input with single output, single input with multiple outputs, and multiple inputs with multiple outputs. The case study sample data contains data from two companies involved in single input with single output, a third company involved in single input with multiple outputs, and the remaining three companies practicing multiple input with multiple outputs of batch processing production (see Appendix B-1a).

Another variable that can influence fitness performance score is the nature of the production operation. Production operations can be classified into two groups, namely: labour intensive operations, and technology intensive operations. Under labour intensive operation, the production system is heavily dependent on the use of manual labour, and the efficiency of the system to some extent is largely dictated by the number of operators available per process. On the other hand, technology intensive production makes use of an automated production line and requires skilled operators to man the machines. The efficiency of the production system is dependent on machine performance. The case study sample contains two companies operating labour intensive production system, and four companies operating technology intensive production system.

Furthermore, Ebrahim (2011) argued that order fulfilment strategies could influence fitness performance score. Other fulfilment strategies can be classified into two, namely: Make-to-Stock (MTS) and Make-to-Order (MTO). Make-to-stock strategy risks over capacity, while make-to-order strategy risks a shortage in capacity. The case study sample contains two companies operating make-to-order production strategy, one company using make-to-stock strategy, and three companies using a mix of MTS and MTO.

Finally, Ebrahim (2011) argued that changes in product design and specification could influence fitness performance score. Changes in product design can occur due to a number of reasons including changes in customer’s taste, product innovation, quality improvement or raw material availability or specification. Changes can be customer led (customer-oriented), or innovation oriented; or market demand.

5.5. Overall Production Fitness Index (OPFI)

The improvement in factory productivity involves metrics to measure and compare the efficiency and effectiveness of production process and equipment. Today, overall equipment efficiency (OEE) is a metric that has been used to control and investigate equipment improvement. OEE is restricted to evaluating the efficiency of the production equipment rather than the whole production process. Oechsner et al. (2003) affirmed that a factory runs effectively if all its components are efficient. Consequently, a metric that can measure the whole factory efficiency is desirable. Therefore, a factory-wide approach for controlling and improving overall production fitness (OPF) is required. OPF means integration of information, decisions and actions across many independent systems and sub-systems, and combining manufacturing capabilities such as leanness, flexibility, agility, responsiveness and sustainability. OPF evaluates the entire value chain, from new product introduction to sales performance.

There is no commonly accepted method or metrics for the measurement or analysis of overall production fitness available now. Ebrahim (2011) proposed a model for evaluating operations performance from specific viewpoint of production capability, termed production fitness. However, the model was deemed to complex and difficult to implement. Consequently, this study proposes a simpler easy to use index for evaluating overall production fitness. The overall production fitness index (OPFI), also called Fitness Index (FI), provides metrics for combining leanness (LI), agility (AI), and economic sustainability (ESI):

$$\textbf{OPFI = (LI) * (AI) * (ESI)} \qquad 5.1$$

Where:

$$LI = \frac{\text{Sales}(\$) - \text{Rejects}(\$)}{\text{Installed Capacity}(\$) + \text{Inventory}(\$)} \qquad 5.2$$

$$AI = \frac{\text{Product Mix Flexibility}(\text{n})}{\text{Changeover time}(\text{k})} \qquad 5.3$$

$$ESI = \left(\frac{\text{Total Paid} - \text{in}(\$)}{\text{Total Paid} - \text{out }(\$)} \; X \; \frac{\text{Actual output per month (or per annum)}}{\text{Maximum possible output per month (or per annum)}} \right) \qquad 5.4$$

Given the definition of the individual components employed in this work, the OPFI model as shown at Eq. 5.1 makes use of *multiplication* of terms as opposed to other mathematical operation. The use of multiplication implies fitness index becomes zero if any of the input were to be zero. For example, if the leanness input is zero, a case whereby the production system produces high level of rejects greater than sales, OPFI becomes zero. It follows; zero leanness, zero agility, or zero sustainability means zero fitness level. From the foregoing, it is evident that factors impacting on OPFI include quality rate, sale performance, finished goods inventory, capacity utilisation, product mix flexibility, and manufacturing system responsiveness to changing market demand. This means that the entire production system value-adding chain and manufacturing capabilities have to be tracked, analysed and aggregated. OPFI metrics provides a snap-shot, accurate, comprehensive, and consistent means to evaluate the overall health of the business. It can be used to provide both instant view of the firm as well as an analysis of the historical trend of the firm’s performance with a view to predict possible future outcomes. The fit index links the efficiency of the production system at producing quality goods using limited resources (leanness), with the production system’s flexibility and responsiveness (agility), against the production system’s efficiency to compete as a sustainable profitable enterprise (economic sustainability).

The OPFI model demonstrates how fit manufacturing is able to integrate activities on the shop floor directly with customer’s satisfaction and patronage as measured in sales figures. The fit model penalise the manufacturing enterprise on rejects, inventory, over capacity installation, and excessive labour cost. The model suggests the best way to optimise the overall production fitness is to:

i. Increase the flow of money coming in through sales of innovative products that meets/exceed customer's expectation and satisfaction

ii. Reduce rejects which can be either defects coming off the production line, or sales return due to product functionality not meeting customer's expectation

iii. Minimise inventory through just-in-time production. Inventory that is not bringing money from outside is a cost, not an asset

iv. Maximise the production system responsiveness and increase value flow through reduced cycle time

v. Fully utilise the installed capacity to support existing product line or introduce new product for the spare capacity

vi. Maximise employee productivity

Figure 5.1 is a flow chart representation of OPFI implementation. The flow chart shows that the process of improving fit index performance is an iterative one of constant re-evaluation of indicators and enablers of the individual component of fit index, namely: leanness, agility and sustainability.

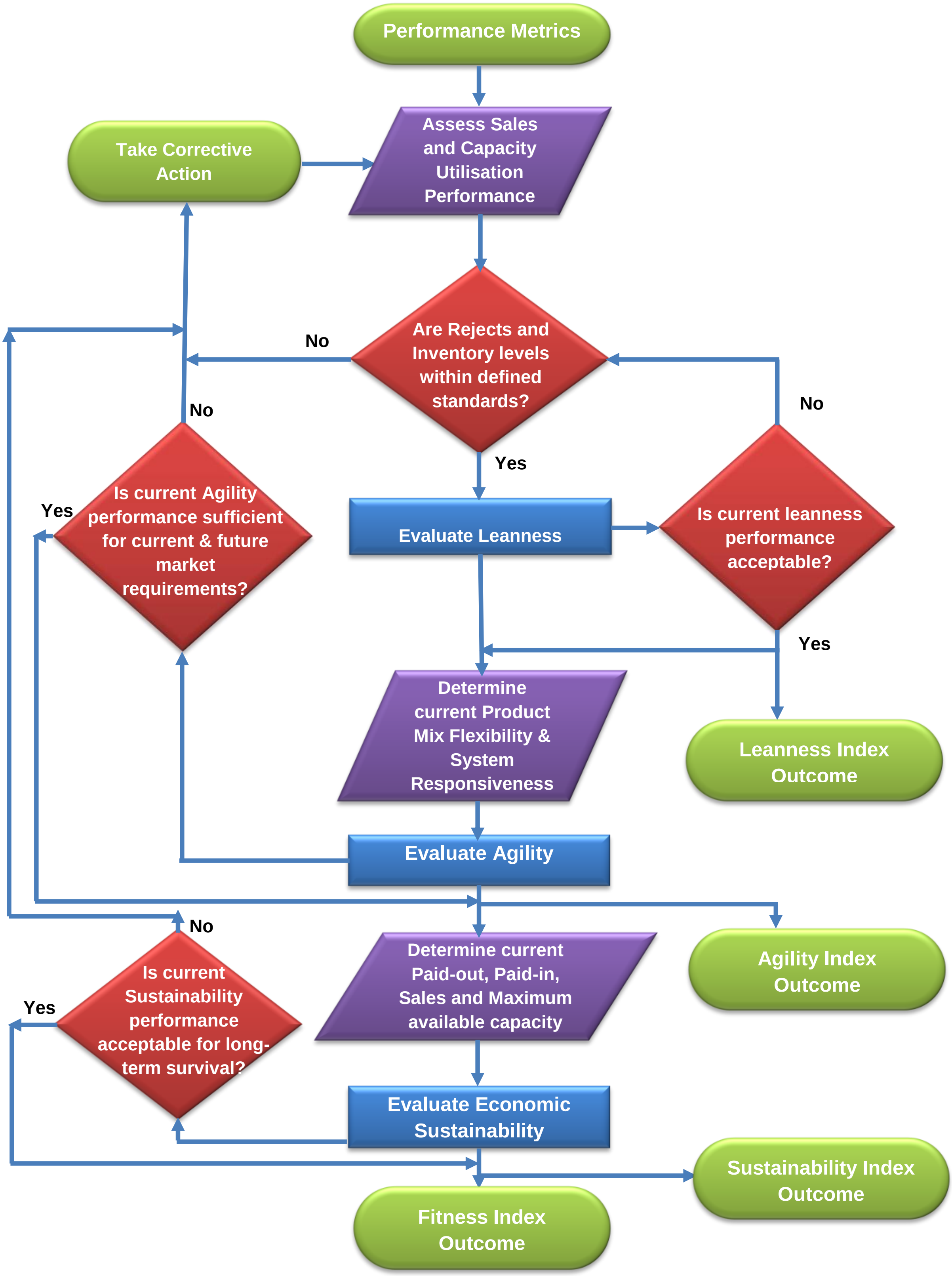


Figure 5.1: Fitness index evaluation flowchart

5.6 Results and Discussion

The discussion of the result is divided into three sections: uni-optimisation, bi-optimisation, and multi-optimisation. Uni-optimisation evaluates isolated implementation of improvement paradigms, bi-optimisation technique assesses a combination of the paradigms, while multi-optimisation technique was implemented to enable a comparison of the performance of the new fit index with current state of practices in the industry

5.6.1 Uni-optimisation

This involves evaluating the individual index against available sample data for 60months between the periods of January 2005 to December 2009. Uni-optimisation approach offers the opportunity to examine the individual companies against lean, agile, and economic sustainability performance measures.

Figures 5.2, 5.3, and 5.4 present the results of leanness, agility, and sustainability assessment for the six manufacturing companies, namely: A, B, C, D, E, and F. The companies are also referred to as Case Study 1, 2, 3, 4, 5, and 6 respectively. Given that the six manufacturing companies are in different industry classification, it is plausible that different market factors influence the performance of these companies across the different industry. Thus, no effort is made to rank these companies according to their leanness, agility or sustainability.

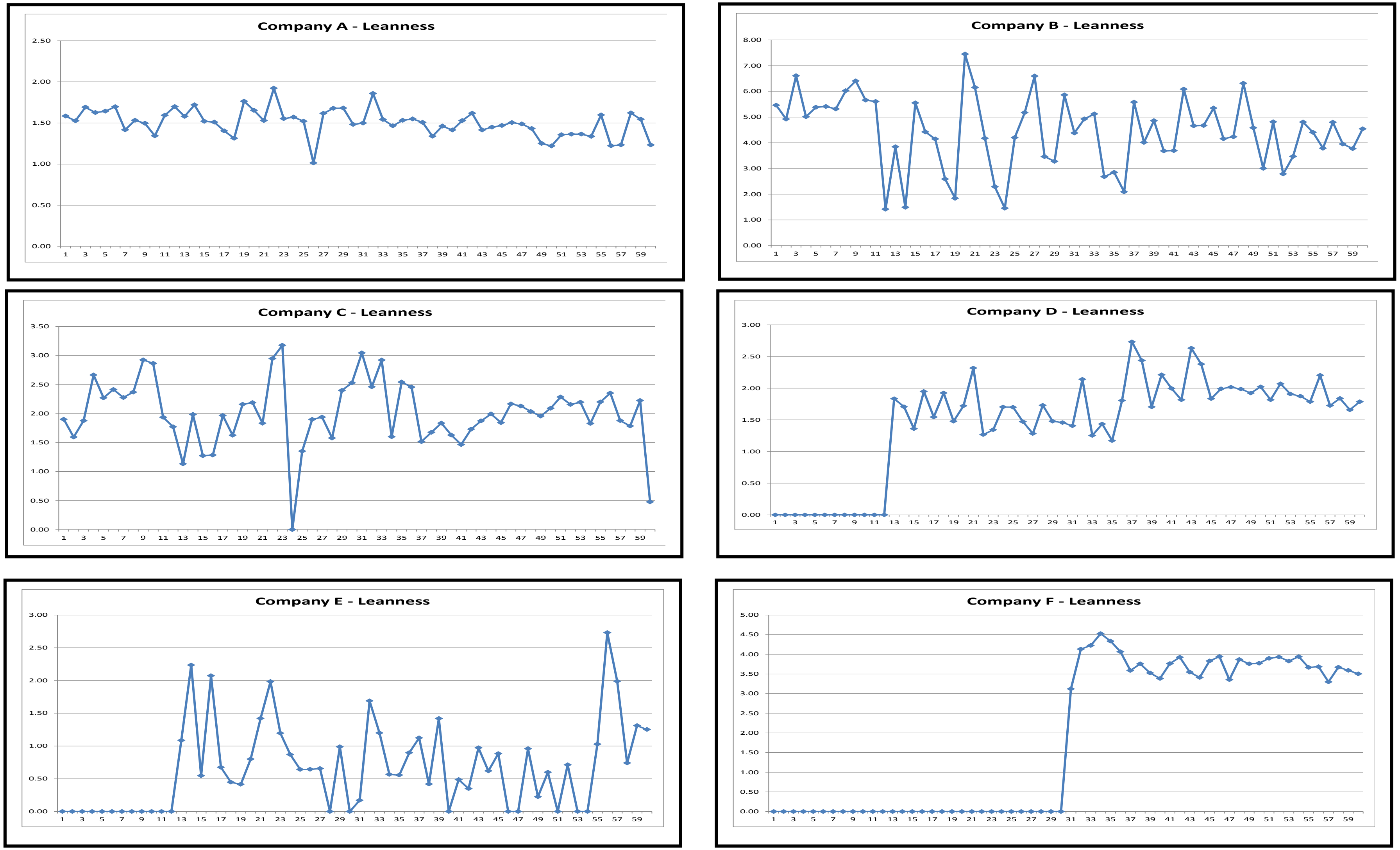
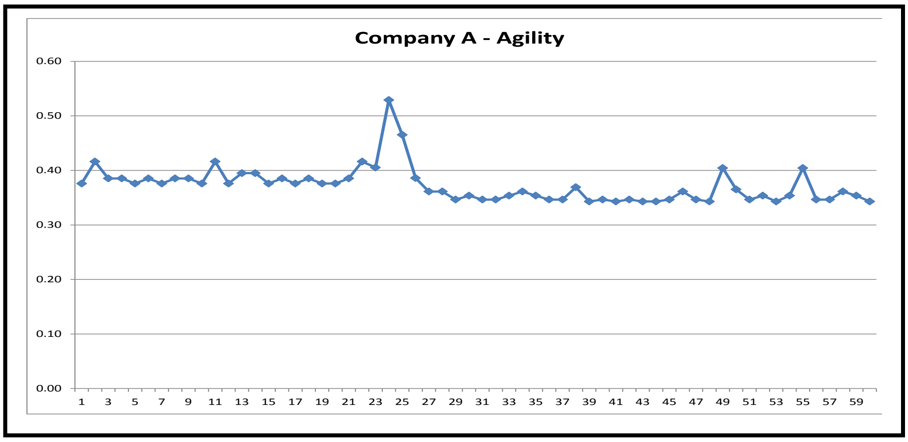
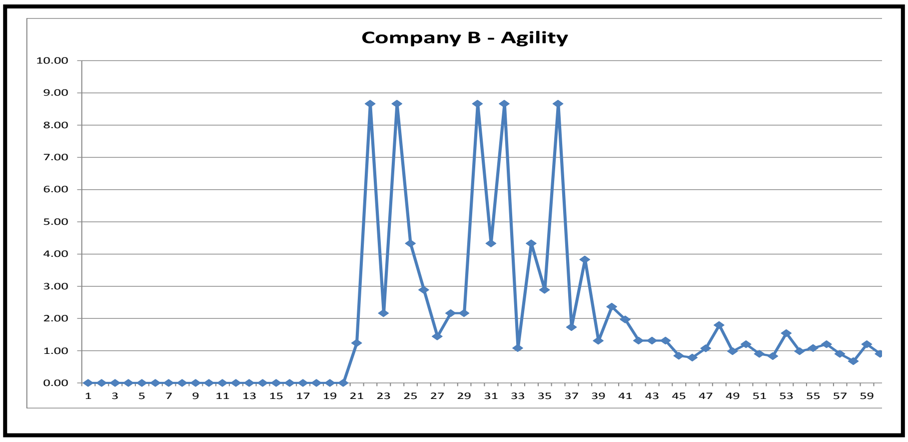


Figure 5.2: Result of leanness assessment for the six manufacturing companies





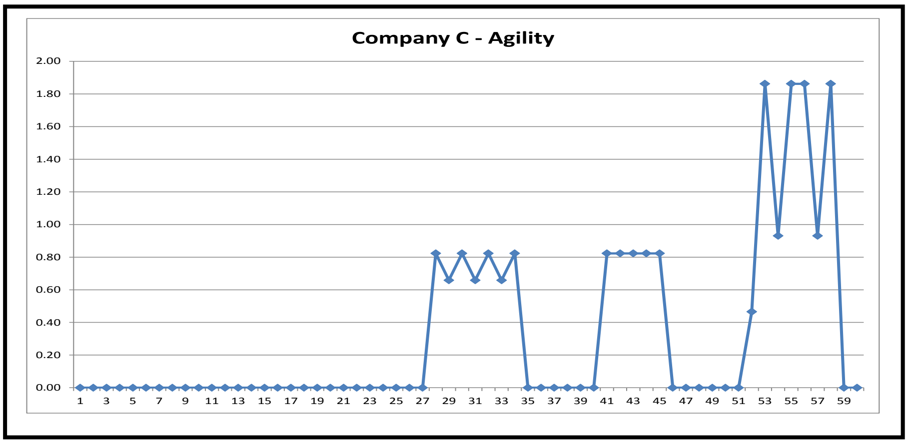


Figure 5.3: Result of agility assessment for case study companies A, B, and C

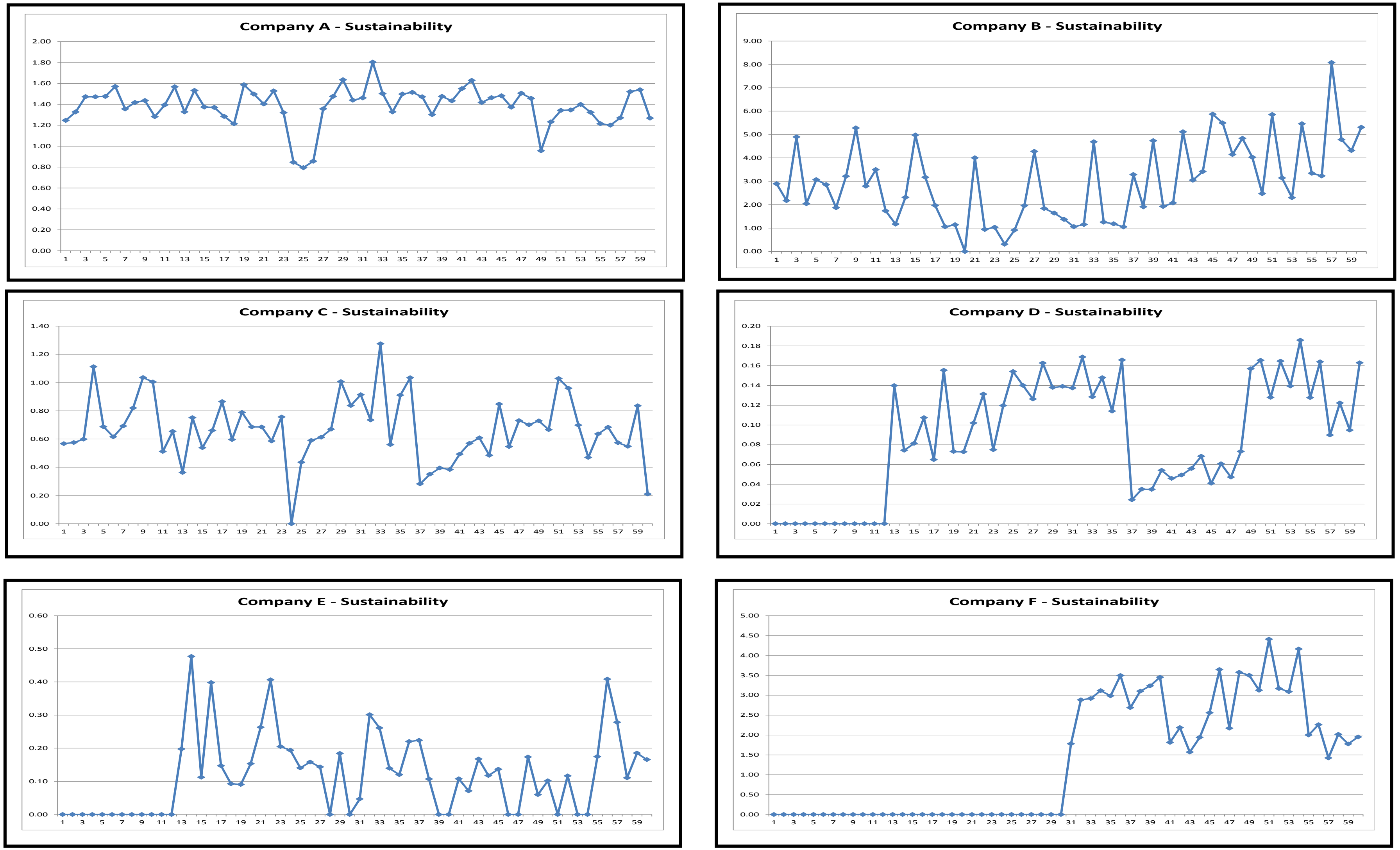


Figure 5.4: Result of sustainability assessment for the six manufacturing companies

performance. More so, there are no captured data to enable agility assessment for companies D, F, and F during the period under review. However, the followings can be deduced from figures 5.2, 5.3, and 5.4.

5.6.1.1. Uni-optimisation: Leanness Index

Figure 5.2 shows that when company's A leanness performance is compared with the leanness performance of the other companies, company's A leanness is stable over the 60 months period. The leanness performance of companies B–F, all consumer goods manufactures, oscillates and thus indicates that the underlining production system at these manufacturers are susceptible to market changes as dictated by product innovation and value-for-money expectations. Both companies E and F operate in the beverages industry, and they both suffer from in-complete data. However, careful analysis shows that the start of lean implementation is usually associated with a boost in performance, and overtime outputs from lean implementation might result in irregular curves, when depicted graphically, depending on how successful the programme is. Finally, figure 5.2 illustrates that there might be a relationship between sales performance and leanness index; if the sales performance is high relative to 'available capacity', leanness performance is also high and vice-versa. This is because lean main focus is waste elimination, either in form of rejects elimination, inventory reduction, or optimisation of capacity utilisation.

5.6.1.2 Uni-optimisation: Agility Index

Figure 5.3 shows the agility performance assessment for companies A, B, and C. Unfortunately, changeover time statistics for companies D, E, and F are not available. However, given the available data, it is possible to comment that outcome from an agile implementation programme can also assume other forms of shapes outside “S Curves” depending on the performance of the underlining production system. Company’s A agile performance can be described as stable, while analysed data indicates that the agile performance of companies B and C fluctuates widely. Perhaps this is due to the type of industry in which these two companies operate.

However, the results for company A, B and C show that in general, range flexibility described as a combination of product variety and volume variety, and changeover time influences agility. For instance, for company A, the size of product variety was 2.49 in 2005 and updated to 3.15 from 2007 onward. The size of volume variety was however 5.00 for 2005-2009, while changeover time for this period varied. Smaller changeover time tends to produce higher level of agile index, for example for the 25th month, the set of agile parameter operating were the size of product variety 3.15; the size of volume variety 5.00; and changeover time 17.52hrs, given an agility index of 0.47. In the 48th month (23 months after), the size of product variety and size of volume variety were the same as for 25th month; but the changeover time was 23.76hrs, given an agility index of 0.34 (see Appendix C-1).

5.6.1.3 Uni-optimisation: Sustainability Index

Figure 5.4 shows the result of sustainability assessment for the six manufacturing companies. Sustainability index measures the profit per unit ratio against factory utilisation efficiency. This ensures that a manufacturer can take a measured approach to the questions:

i. Should installed capacity be increased because of better than expected profit per unit of production?

ii. Should the focus be on how to improved profit per unit rather than how to increase available capacity?

iii. What combinations of profit per unit and utilisation efficiency are required to achieve long-term sustainability?

Comparing the outcome of leanness performance illustrated in figure 5.2 with figure 5.4, it can be argued that there exist a close relationship between the attainment of sustainability goals and leanness, perhaps due to lean being the basic criteria for a competitive performance. In addition, the similarity between these concepts reflects the importance of capacity utilisation efficiency in achieving leanness performance objective and the long-term sustainability of the enterprise. From figure 5.4, it can also be argued that higher scores of sustainability index does not necessarily indicates a good sustainability performance but the consistency of the system performance overtime. For example, for the period under review, company B has higher sustainability scores but suffers a lot of fluctuations compared with company A where the sustainability scores are quite small but the system is much stable, and therefore easier to control and manage.

Finally, within the context of uni-optimisation, it can be argued that given limited resources and market constraints, a manufacturing company looking to achieve fitness should consider the implementation of economic sustainability initiative because this contributes the most towards the overall survivability and profitability of the enterprise

5.6.2 Bi-optimisation

Under bi-optimisation, the combinations of (i) lean and agile; (ii) lean and economic sustainability; and (iii) agile and economic sustainability implementation are examined. Bi-optimisation offers the opportunity to examine the case studies companies along two dimensions.

5.6.2.1. Bi-optimisation: Lean and Agile Combination

For the purpose of this work lean was defined as the ratio of quality sales to total available capacity; while agility was defined as the ratio of product flexibility to changeover time. Given the way lean and agile have been defined in this work, there is limited evidence to show a strong correlation between the two paradigms. However, figure 5.5 appears to suggest that when lean index is increasing, agility tend to increase or remains stable, whereas a decreasing leanness performance does not necessarily means a decrease in agility performance.

This paradox is best understood against the background that increased leanness performance is mostly driven by just-in-time capability to enable quality sales to efficient capacity utilisation. Thus, leanness performance is enabled by increased product flexibility and quick changeover time. This implies more quality sales are likely, with less waste, if the production system is able to handle customised products at short notice.

Figure 5.5: Bi-optimisation - lean and agile combination

On the other hand, a decreased in leanness performance does not signify problem with product flexibility or changeover time. Often, leanness performance scores decreases because of quality issues, inventory level, and sales performance.

5.6.2.2. Bi-optimisation: Lean and Economic Sustainability

In section 5.6.1.2 it was argued that there exist a close relationship between the attainment of economic sustainability goals and leanness. Figure 5.6 further highlights this relationship, showing that as leanness increases sustainability also increases, and when leanness decreases sustainability also decreases. As previously mentioned in section 5.6.1.2 attainment capacity utilisation efficiency is an important goal of both lean and economic sustainability. Under lean paradigm, under-utilisation and over-capacity are targeted waste for reduction or elimination, whereas, under economic sustainability, capacity utilisation efficiency is considered an enabler of long-term survivability and profitability.

Figure 5.6: Bi-optimisation - lean and economic sustainability combination

5.6.2.3. Bi-optimisation: Agility and Economic Sustainability

Figure 5.7 highlights the relationship between agility and economic sustainability; the figure shows that when agility performance scores are stable, economic sustainability performance scores are also likely to be stable. Conversely, when agility performance scores fluctuate, economic sustainability performance scores are also likely to fluctuate. A plausible explanation for this observed correlation relationship is that agile performance scores and economic sustainability score are consequences of common causes, though the two do not cause each other. Agility represents the ability to implement responsive production system that can be quickly reconfigured to take advantages of market changes. Sustainability on the other hand represents the capacity of the production system to ensure long-term survivability of the firm. Thus, the correlation relationship between these two paradigms is a form of predictive relationship that can be exploited.

In addition, this provide an opportunity to compare the efficiencies achieved through uni-optimisation with bi-optimisation and examine the cost implication of extending implementation of FM beyond one dimension to two dimensions of leanness, agility and sustainability.

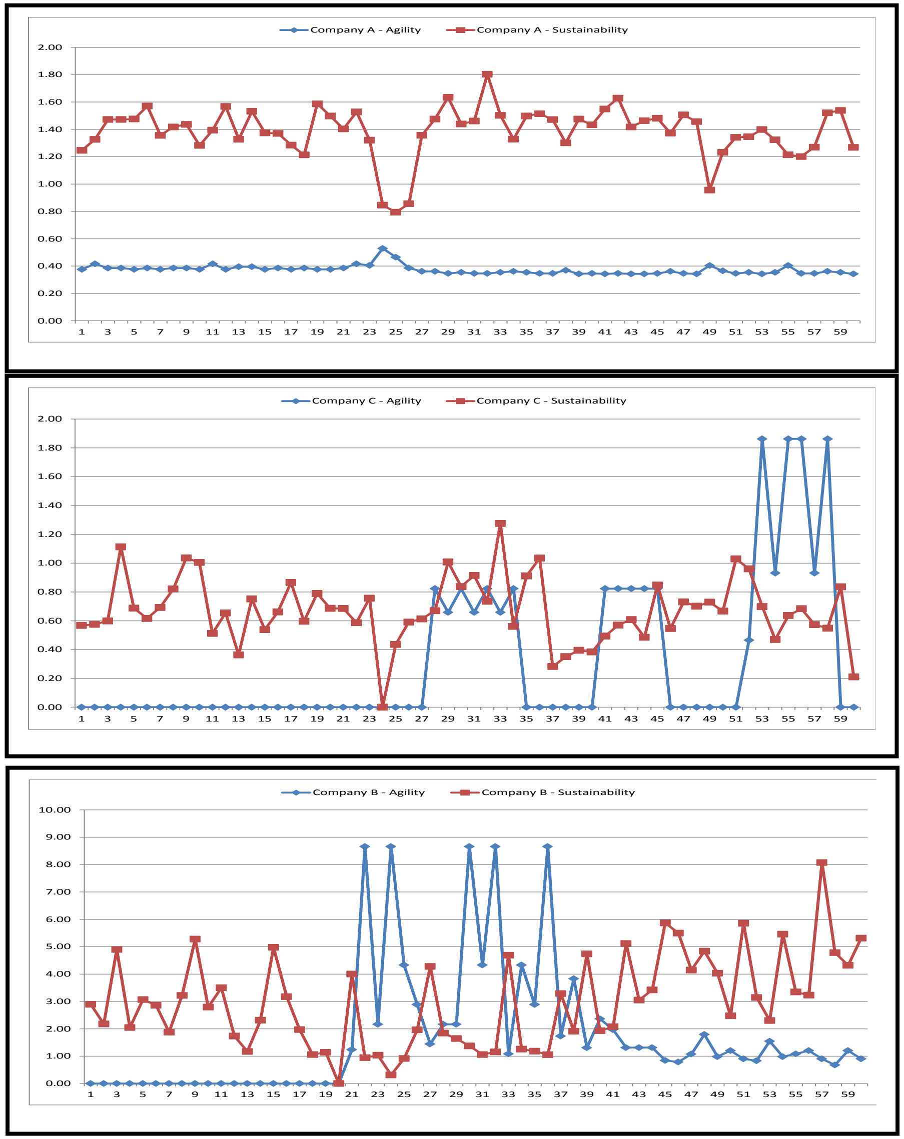


Figure 5.7: Bi-optimisation - agility and economic sustainability combination

5.6.3. Multi-optimisation

In sections 5.6.1 and 5.6.2 uni-optimisation and bi-optimisation approaches to the implementation of leanness, agility, and sustainability were discussed. This is because some companies are only interested in the implementation of just one of the manufacturing initiatives of lean manufacturing, agile manufacturing, or economic sustainability. Such firms may not necessarily be interested in the integration of the three dimensions of fit manufacturing.

Likewise, multi-optimisation of leanness, agility, and sustainability as depicted by figure 5.8 provides opportunities for managers to compare the production system performance along the three dimensions simultaneously. The qualitative result can be used by management to investigate the conditions that enable optimised performance and the conditions that constraint desired system performance. For example, case study company A had its highest leanness performance in the 22nd month, and its lowest leanness output occurred in the 26th month, the same month when the sustainability performance was close to its lowest outcome. Therefore, for an overall optimised production system performance, it is suggested that the management of this company investigates the factor(s) responsible for the two different levels of performance outputs in order to better understand and better manage the production system given varying market conditions.

Furthermore, figure 5.8 provides opportunities to examine the integrations of the improvement initiatives with and without the agility component given that there are no available historical data on agility for case study companies D, E and F for the period under review, 2005 - 2009. From figure 5.8 the followings can be deduced:

i. There is a predictive relationship between leanness and sustainability because the performance objectives of the two paradigms are quite close such that it can be said "a wasteful enterprise is not sustainable, and a lean enterprise with less waste is likely to be sustainable".

ii. An enterprise leanness performance is enhanced where there are agility enablers of product flexibility and changeover time.

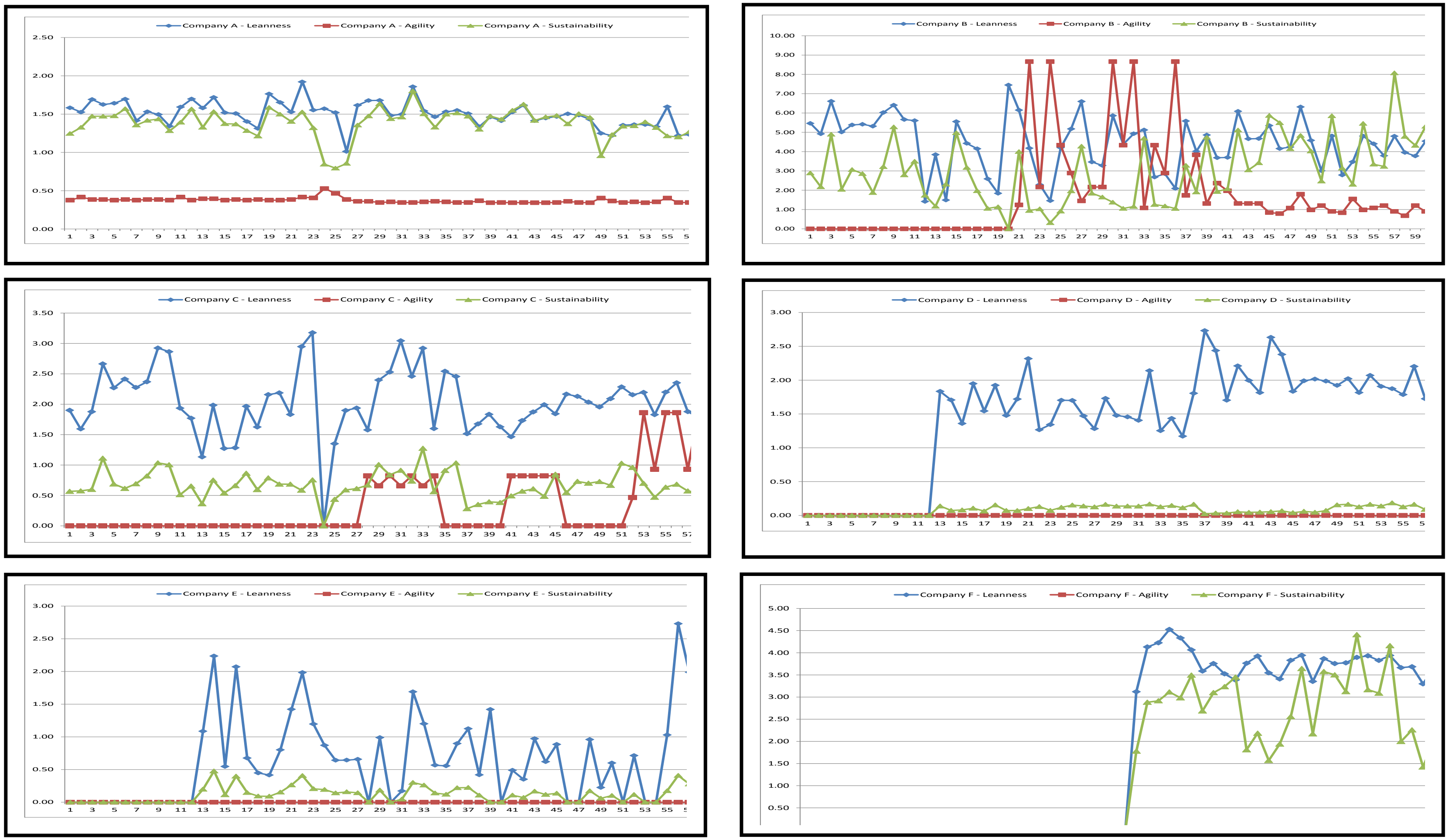


Figure 5.8: Multi-optimisation of leanness, agility and economic sustainability

iii. Given the outcomes of the analysis of companies D, E and F as shown in figure 5.8, a sustainable enterprise does not necessarily have to be agile (been able to offer product variety) but must be lean efficient (able to make and sell quality products, and achieve capacity utilisation efficiency). This statement is especially true is some industries where mono-product is on offer or the industry is dominated by monopolists. The shapes of the competition in such industries are driven by competing forces other than time management and product flexibility.

iv. As previously stated in section 5.6.2.3, there is a correlation relationship between agility and economic sustainability such that given volatile market conditions, agility performance under the condition of market unpredictability significantly influence the enterprise sustainability.

5.7. Overall Production Fitness Index (OPFI)

The multi-optimisation analysis done at sessions 5.6 involves evaluating the case study companies against the three dimensions of fit manufacturing. In this session effort is made to develop a single fitness index called OPFI that integrates the three dimensions of fit manufacturing. Such index is especially useful not only in assessing the fitness scores of manufacturing firms, but can also aid in ranking manufacturing companies along the dimension of fitness. In addition, the fitness index can be used:

i. To analyse fitness trend in order to take corrective action or to assess qualitatively current performance outputs

ii. Make investment decision so as to determine what levels of leanness, agility, economic sustainability, or a combination of strategies is required to enable the production system to compete successfully

iii. Evaluate competing priorities or product portfolio so as to allocate or deploy resources to meet current and future challenges

From 5.1 overall production fitness index (OPFI) was defined as:

$$OPFI = (LI) * (AI) * (ESI)$$

Figure 5.9 presents the OPFI for the six case study companies. For case study companies D, E, and F there was no data on agility for the period under review. Subsequently, agility index was set to 1 to enable OPFI to be determined, i.e.

$$OPFI = (LI) * (ESI)$$

When AI = 1

Two set of comparison of the results presented in figure 5.9 are done. Companies A and B with data on all the three dimensions of fitness are compared, while companies C, D, E and F with missing data on agility are also compared for analysis; and then the six case study companies are compared all together.

5.7.1 Comparison of Companies A and B

Using the established model, OPFI = (LI)*(AI)*(ESI), figure 5.9 indicates company B has higher fitness index performance than company A. However, the fitness performance of company B assumes values in the range of 0.00 to 70.00 while company A's fitness performance is confined to a narrower range of 0.30 to 1.20. Company A is a semi-finished goods manufacturer of rubber and plastic products (plastic plate, sheets, tubes and profiles) while company B is a consumer goods manufacturer of fertilisers. The difference in the fitness performance of company A and B perhaps could be explained by the nature of competition in the two different industries where these two companies operate. Within the rubber and plastic products industry, the nature of competition is driven by the requirement to achieve leanness, that is, greater product quality, cost efficiency, and product value. Whereas, in the chemical industry it is plausible that emphasis is on both agility and leanness. The requirement for agility is driven by the need to offer product range flexibility while reducing changeover time, and while leanness requirements is defined in terms of cost efficiency and product quality.

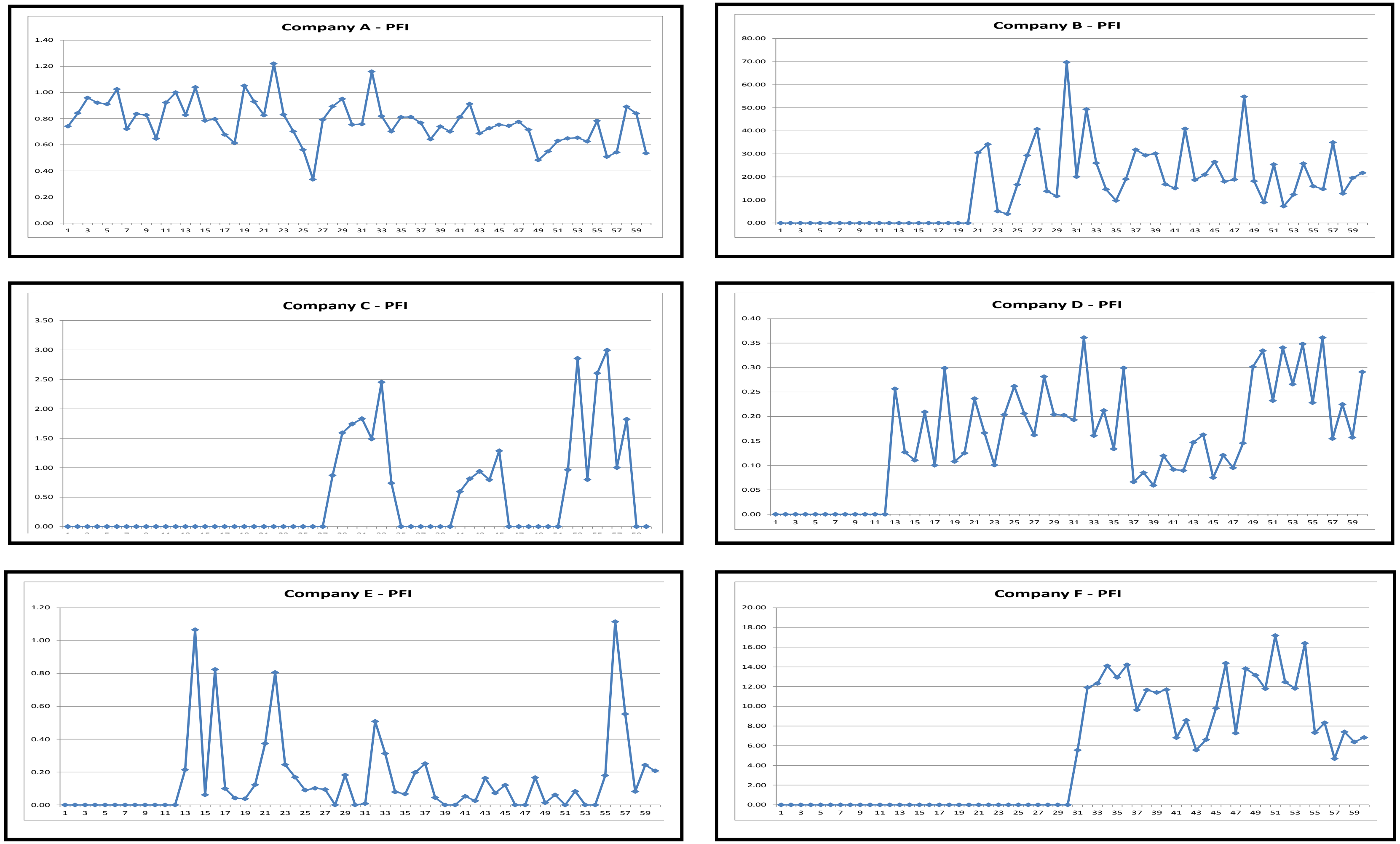


Figure 5.9: Overall production fitness index (OPFI)

5.7.2 Comparison of Companies C, D, E and F

The comparison of companies C, D, E, and F highlights fitness performance in situations where there are no defined data on agility. The four companies are all consumer goods manufacturers - company C is into processing and preservation of sea food (fish, crustaceans and molluscs), company D is a chemical manufacturer producing cleaning and polishing products; while companies E and F are both manufacturer of beverages. From figure 5.9 it can be seen that company F has the highest fitness scores with a peak score of 18.00. Company D has the lowest ranked fitness scores achieving a peak score of 0.38 (Appendix C-4). However, qualitative analyses of fitness performance for the four companies reveal oscillating fitness curves. It is possible that the observed volatility in the shapes of the fitness curves is due to the fact that all the four companies are consumer goods manufacturers. Traditionally, the consumer goods industry faces constantly evolving market dynamics which are influenced by a number of factors including cost pressure, intense competition, shifting consumer taste and flexible order fulfilments. Available evidence appears to suggest that these environmental factors influence significantly fitness performance scores.

5.7.3 OPFI as a Ranking Tool

Section 3.8 defines fitness index as the output of a manufacturing company against leanness, agile and sustainability performance enablers. It was stated that the operation of a manufacturing firm continually generates new fitness scores against which its long term economic sustainability is assessed. This helps the organisation to evaluate its future prospects of survival. In addition to using fitness index to evaluate the long-term profitability and sustainability of a firm, the index can also be used to rank manufacturing companies on the basis of highest fitness score achieved. For example, from figure 5.9 it can be seen qualitatively that company B achieves the highest fitness score of 69.72 followed by company F with a score of 17.17; company C with a score of 2.99; company A with a score of 1.22; and then company E with a highest fitness score of 1.11; and finally company D with a highest fitness score of 0.36.

Furthermore, a comparison of the performance of companies E and F, both beverage manufactures, indicates that company F significantly outperform company E. Company F achieved fitness performance scores which range from 3.80 to 17.17, while company E fitness scores range from 0.01 to 1.11. A plausible explanation for the observed difference in the fitness performance of these two competitors is that company F has better operational fundamental in terms of leanness and sustainability performance indicators. The leanness result of company F shows that the company achieves leanness scores which range from 3.12 to 4.52 and economic sustainability scores from 1.57 to 4.41. On the other hand, company D achieve leanness scores which range from 0.17 to 2.73, and economic sustainability scores from 0.05 to 0.48 (see Appendixes C-4 and C-5). The noticeable weaknesses in company D's performance can therefore be attributed to a number of factors including low capacity utilisation implying the company carries "excess fat to requirement". Thus for company D to improve its fitness performance, the company management have to determine the levels of leanness, agility, economic sustainability, or a combination of strategies that is required to enable the production system compete successfully.

Finally, it is important to state that the problem of using fitness score to rank companies suffers from the usual limitation associated with tools of this nature which is the analysis is based on historical data which may not adequately reflect future performance. However, by conducting an analysis of fitness performance a firm is better equipped to chart a successful future and long-term competitiveness.

5.8 Validation of Research Hypothesis

In section 3.8 the research hypothesis was stated as: over a period of time fitness outcomes take the shape of an “S Curve” when depicted graphically. It was assumed that fitness is a function of time and not an end state; and the slope of the fitness curve for a company indicates whether its fitness level is increasing, decreasing or static. It was stated that a negative slope signals a decline in the overall health of the business. If this were to persist, it would eventually lead to failure of the company. The performance of a fit firm was compared to that of a top athlete whose time progression performance takes the shape of “S curve”; and possesses the following attributes:

i. Ability to develop techniques and skills required to compete successfully

ii. Ability to replicate and shorten the time between successful outcomes -stride frequency

iii. Ability to develop the stamina, a discipline focus, superior flexibility, and physical fitness required to compete

iv. Ability to stay injury free in order to reduce the athlete vulnerability and increases the chances of long-term career

v. Ability to overcome existing speed barriers in order to deliver a world-class performance.

The above attributes for a fit performing top athlete was used as an inspiration to describe the operational characteristics of fit production philosophy. In section 3.81 it was presented that a fit firm possesses the following attributes, namely: goal driven, competitive, stride frequency, innovative, flexible, responsive, and self-renewal.

From figure 5.10, it can been seen qualitatively that the 100m progression performance of the fastest man in the world, the ideal fit athlete, shares similarities to the case study companies' fitness performance analysis. Consequently, given the historical data used for this work, all the six case study companies can be said to be 'fit' though the degree of fitness differs. In addition the following research statements can be affirmed:

i. Fitness curve takes the shape of "S Curve" when measured overtime

ii. The slope of the fitness curve for a company indicates its degree of fitness and describes the rate at which the firm replicate successful outcomes. Degree of fitness (DF) between two points can be calculated as follows:

$$DF = \frac{P_2 - P_1}{t_2 - t_1} \qquad 5.5$$

Where:

$DF \leq 1$

P_2 is second chosen point of the slope at time t_2

P_1 is first chosen point of the slope at time t_1

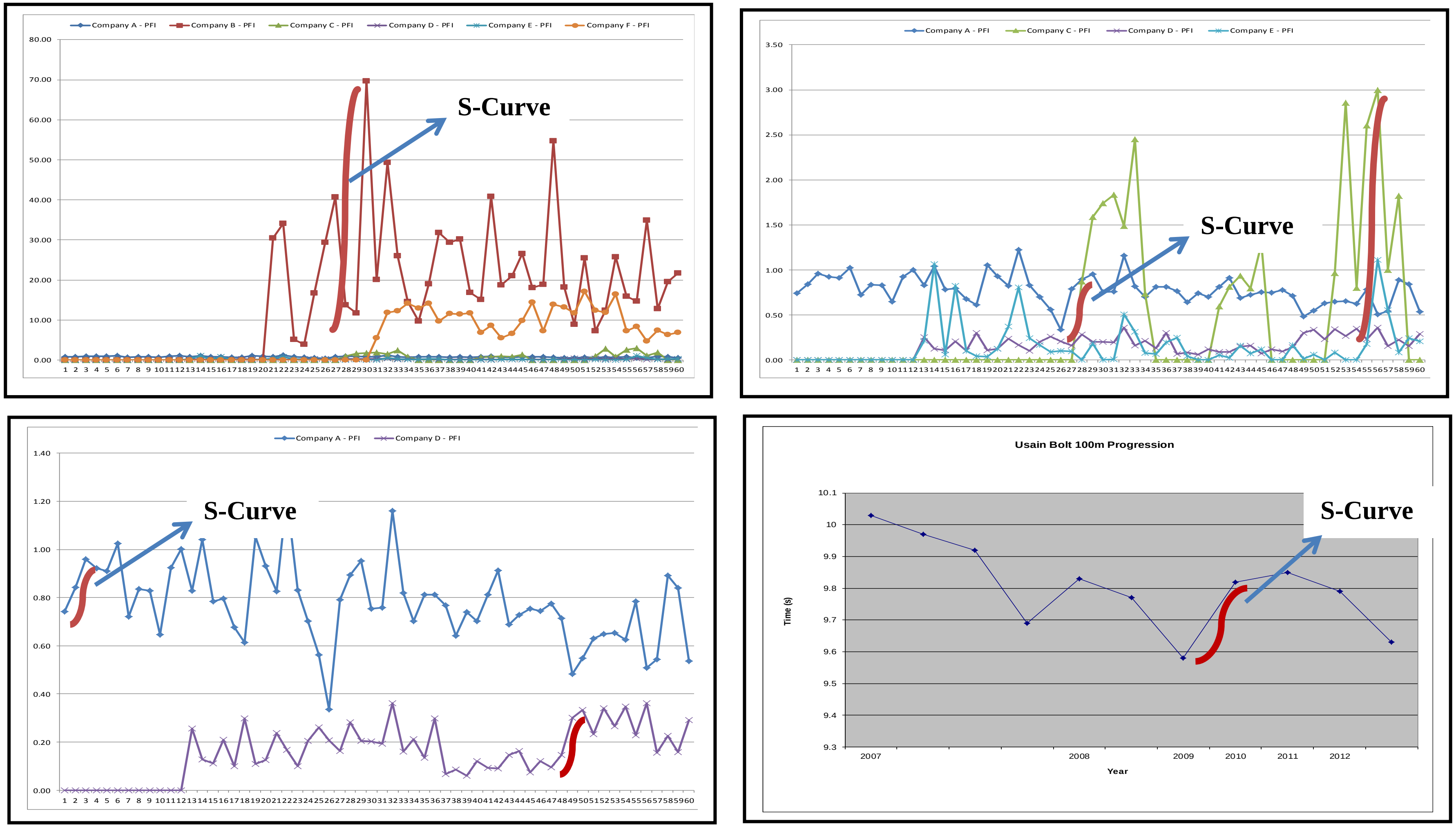


Figure 5.10: Family of fitness curves

The degree of fitness is a measure of a firm’s efficiency and fitness level. The most efficient firms usually achieve higher levels of degree of fitness, and are ranked first before other firms. A manufacturing firm’s degree of fitness can also be used as a measure to optimise the firm’s performance, and improve its fitness level. A firm’s degree of fitness is comparable to an athlete stride frequency, a measure for optimising an athlete’s running form and technique.

iii. A negative degree of fitness signals a decline in the overall health of the business. If this were to persist, it would eventually lead to failure of the company.

iv. A fit system is able to cope with a step change or continuous change induced internally or externally, and adjusts itself overtime without suffering a sustained declined which could lead to a total failure.

v. The operation of a manufacturing firm continually generates new fitness scores against which its long term economic sustainability is assessed.

5.9. Necessary Conditions for Fitness

At section 5.1 fitness index was defined as:

$$FI = (LI) * (AI) * (ESI)$$

Given the above equation, and based on the data analysis conducted in this work a production system is said to be fit whenever all the three following conditions are met

1. Lean Index (LI) > 0

If Lean Index (LI) <= 0

Then Fitness Index (FI) = 0 5.6

This condition affirms that leanness can never be less or equal to zero this is because negative (Sales < Rejects) or zero leanness (Sales = Rejects) signifies situations whereby there is serious quality problems at the manufacturing company. The attainment of leanness goals for any manufacturing company is considered as basic criteria that every company must operate just to remain ‘players’. This is due to that fact that most manufacturing systems conforms to the basic principle of lean manufacturing. Whereby, a manufacturing system is able to work well given relatively stable and predictable demand, and low product diversity.

2. Agile Index (AI) > 0

If Agile Index (AI) <= 0

Then Fitness Index (FI) = 0 5.7

This second condition for fitness affirms Agile Index (AI) can never assume a negative value or equal to zero because agility is an added-on condition on leanness. More so, a zero agile value signifies a manufacturing system that is unable to deliver value to the customer. This condition can only occur when the range of product mix available is less than 1. However, it is possible in some industry that product range flexibility and changeover time are not considered as necessary conditions to be competitive.

3. If Sustainability Index (ESI) = -1 5.8

Then Fitness Index (FI) < 0

Condition three implies fitness can take on both positive and negative values. Negative values indicate the fitness level is in decline due to losses, and cost of doing business being greater than profit. Positive values indicate the manufacturing system is able to maintain steady states or is in growth state beyond current boundaries.

4. It follows from condition three that: there is an equivalent relationship between fitness and sustainability, such that if the entity is not fit, it cannot be described as sustainable, and if it is sustainable it is fit. Consequently, the equivalent relationship can be described as:

$$A = B$$

$$\text{and} \quad B = A$$

This implies the attainment of one goal equals the attainment of the other. Figure 5.11 illustrates the relationship between fitness and economic sustainability, and figure 5.12 shows this relationship for the case study companies.

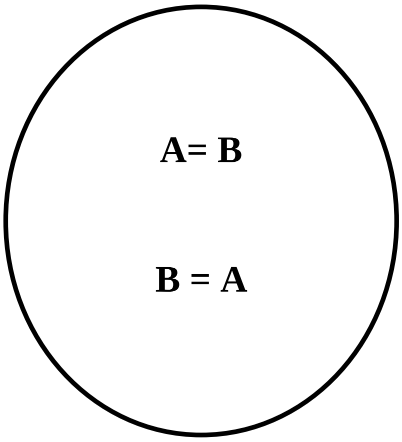


Figure 5.11: Attainment of fitness and economic sustainability goals

Where:

Fitness = A

Economic Sustainability = B

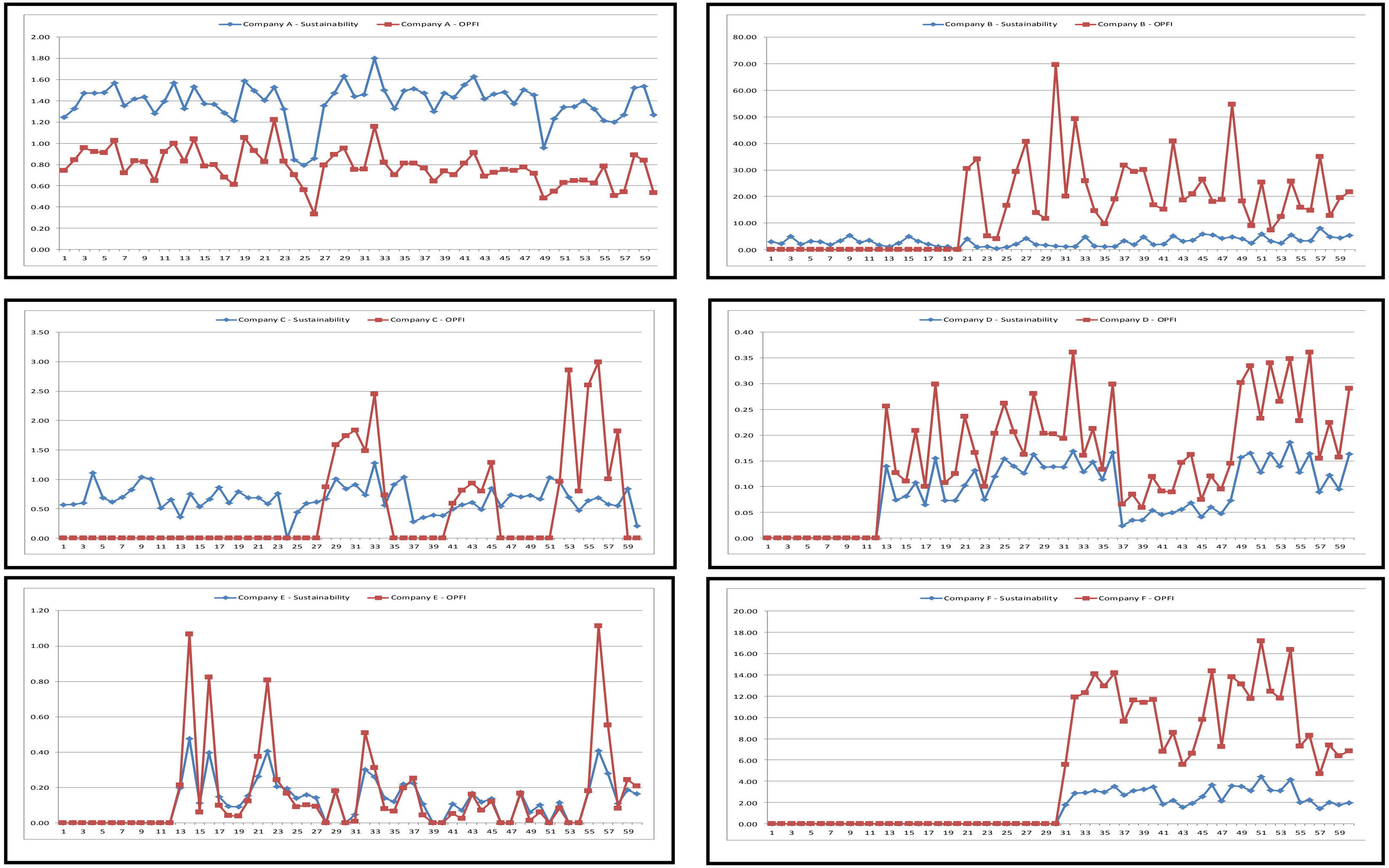


Figure 5.12: Relationship between fitness and economic sustainability

5. Condition five affirms that there is a predictive relationship between leanness and fitness, such that as one variable (leanness) increases, the other (fitness) increases accordingly. Consequently, the implementation of leanness on its own in most industry may provide sufficient conditions to achieve long-term fitness. However, the focus on short-term goals of quality, waste reduction, time, and inventory management might not be sufficient to manage the enterprise long-term sustainability project. The management of other variables such as production cost ratio, product innovation, and capacity utilisation ratio are equally important. Condition five provides a probable explanation for the demise of some lean organisations, which is, leanness not equal to fitness, i.e.:

$$\mathbf{LI \neq FI} \qquad 5.9$$

Condition five also in a way justifies the need for manufacturing firms to go beyond the achievement of lean manufacturing goals in order to achieve long-term sustainability and fitness. Figure 5.13 illustrates relationship between leanness and fitness for the case study companies. Qualitatively, it can be seen that leanness performance is a predictor of fitness level.

Figure 5.13: Relationship between fitness and leanness

5.10. Benefits of OPFI Implementation

Fit index successfully extended the integrated system concept beyond ordinary manufacturing capabilities; it delivers the benefits of integrated manufacturing system which include increased manufacturing system robustness, improved control and co-ordination, improved quality and timeliness of information, and greater system cohesion. Improved overall system performance helps to reduce time and cost, minimise or eliminate waste, reduce fragmentation and disjointedness, remove duplication, inconsistencies and incompatibilities. However, too tight integration could also result in operational inflexibility and increased system complexity.

In addition, fit index provide a strong indication to evaluate the overall well-being of a manufacturing firm competitiveness as opposed to using profitability index. This is because the fit index indicates the shop floor performance in relation to market conditions. Fit index provides a useful picture of the production system actual operating capability in terms of the system's leanness, agility, and sustainability, three key enablers of long-term competitiveness. Profitability index, on the other hand, does not necessarily show how effective the production system is in relation to market conditions because all cash flows into the enterprise are considered. Thus, using profitability index on its own to measure a manufacturing firm's overall competitiveness and sustainability may not necessarily give the correct decision because it is possible for a firm to report high level of profitability index while the production system is deficient in key manufacturing capabilities. This is because profitability index can be influenced by factors including sales promotions, selling price inflation, and first mover advantage, all of which are not a reflection of the production system performance in relation to long-term competitiveness, and sustainability.

Fit Production System (FPS) is driven by the simultaneous development of a company's long-term strategic continued existence (*sustainability*) and operational competitiveness (*leanness and agility*). Manufacturing fitness combines lean and agility and integrates these approaches into a framework that allows a company to tune its technological capabilities and operational demands with its overall strategic visions. This allows companies to configure their operational strategies to achieve an optimum level of leanness and agility that meets current and future customer demands and one that is compatible with their internal operating structure (Thomas and Pham, 2004). Integrating the various elements of production systems is crucial so that they can work in concert together to achieve greater effectiveness and competitiveness. System integration is also about adding value to the system and increasing its capabilities. Under fit manufacturing model, the two concepts of lean manufacturing and agility are integrated with the overall business strategy along the line of dimensions of sustainability, manufacturing efficiency, marketing strategy and business performance. Effective integration of all the subcomponents of a manufacturing system is a major benefit that can be derived from implementation of fit manufacturing paradigm.

5.11. Summary

This chapter presented a new fit index, also called overall production fitness index, as the output of a manufacturing company against leanness, agile and sustainability performance enablers. Historical data from six case study companies were used to validate the research hypothesis. The six case study companies can be classified as micro-SMEs and operate in four different industrial sectors. Consequently, the justification for fitness index was based on the need to measure production fitness of a firm using factory-wide approach rather than an industry specific method. A fitness index evaluation flowchart was developed as a tool to guide the implementation of the fitness index. Results of the data analysis provided empirical evidences for establishing necessary conditions for fitness and long-term sustainability.

Empirical results and analysis provided justification to affirm that sustainable competitive advantage is gained from the integration of the three improvement paradigms making up fit manufacturing. It was argued that fitness index implementation allows for the evaluation of not only isolated or integrated implementation of leanness, agility, and economic sustainability but also provide a tighter integration between operational short-term goals and long-term goals of economic sustainability of a manufacturing firm. Finally, the research hypothesis was validated and the benefits of OPFI implementation discussed.

Chapter 6

Conclusion

"In this era of mass customisation and turbulent market environments, the general application of lean and agility are no longer adequate; to proposer companies should aim to be fit". Pham D.T and Thomas, A (2005).

6.1. Contributions

This work successfully extends the concept of integration beyond ordinary manufacturing functions into the realms of strategic thinking. The research introduced and established new knowledge, techniques, and concepts useful for managers to address the difficulties of today's business environment. Relevant and useful insights were provided into existing manufacturing strategies of lean and agile manufacturing paradigms. But most importantly, this work integrates sustainability with lean and agile manufacturing initiatives and therefore extends the strength of lean and agile beyond the current application as strategies for production management to a holistic initiative for managing the fitness and longevity of the enterprise.

In addition, an attempt was made to ensure that the new manufacturing concept introduced, can pass the rigorous test of conditions; that is (i) "Does the new production model integrates efficiencies achieved through the implementation of lean and agile production strategies?" (ii) "Is the new production model easy to implement without adding additional complexity to an already difficult manufacturing environment?" (iii) "Will it provide new and useful insight into the manufacturing process for management to rely on in making business decision?" The approach of testing the new manufacturing concept against these simplified criteria guided the completeness of this work. Consequently, the contributions of this research include:

i. *A theoretical framework for fit manufacturing implementation*. The concept of fit manufacturing model was presented in this work as a model that can be utilised to re-think manufacturing strategies. Giving these turbulent times, fit manufacturing concept was developed to offer manufacturing managers and researchers opportunities to look beyond process improvement techniques as panacea for long-term business competitiveness and survival. The justification for fit manufacturing, as a strategic shift, was premised on the need to integrate the strengths of leanness and agility with sustainability in order to deliver long-term enterprise fitness. The research objective (i) to provide a theoretical framework for fit manufacturing was achieved through the development of an integrated production system.

ii. *Simplified operational metrics for leanness, agility, and sustainability based on the theme of integration*. Within the context of fit manufacturing as an integrated manufacturing initiative, three indexes one for leanness, agility, and economic sustainability were developed. The features of lean and agile production systems were investigated and new methodologies for measuring these concepts were defined. Economic sustainability was also established as a distinct concept connected to long-term survivability of manufacturing firms. A sustainability index was subsequently proposed. Thus research objective (ii) to develop simplified practical metrics for the three components of fit manufacturing was achieved.

iii. *A simple and practical metric for measuring the fitness of a production system*. The fundamental nature of fitness within the context of fit manufacturing initiative was clarified and established. In order to evaluate the intrinsic nature of fit manufacturing, an index was developed through the integration of the three core components of fit production system. The convergence model offers superior manufacturing initiative that leads to the development of fit enterprises capable of delivering sustainable benefits in an ever changing complex environment. The development of a fitness index presented in this works means objective (iii) was achieved.

iv. *A simple rule base for fitness.* An analogical study of the fitness performance of a top athlete was proved to be compatible with the performance fit manufacturing system overtime. The analysis provided insights into the dynamic conditions that shape fitness and how superior performance can be achieved and maintained.

Thus, using the inference method of backward chaining, a rule base for fitness was developed and utilised to validate the research hypothesis. This implies research objective (iv) was achieved.

v. *Necessary conditions for fitness within the context of fit manufacturing*. The implicational relationships necessary for the achievement of long-term competitive fitness were examined. The necessary conditions evaluate the operational performance of a production system and its long-term viability against leanness, agility, and sustainability enablers. The implicational relationships between fitness and the three core components assess the production system capability to meet competitive priorities. Conditions under which operational performance indicators of quality, flexibility, and innovation can contributes to overall fitness performance were clearly defined and justified. Thus, research objective (v) was achieved.

6.2. Conclusions

In an era of resource optimisation fit manufacturing marks a breakthrough in convergence of manufacturing models, combining the waste and quality focus of lean, the product customisation and flexibility of agility, with the long-term sustainability and viability capability of economic sustainability. While the fit model can be used to assess the performance of the production process based on current products offerings, the model can also be used to evaluate investment proposal such as adding new product line or increasing the overall capacity of the factory.

Fit manufacturing can thus be argued to have broken the boundary between production process, sales performance, and return on investment (ROI). This integrated capability makes the fit manufacturing model a tool for not only monitoring short term goals of production efficiencies but also long term goals of profitability and sustainability. The fit manufacturing model can also be argued to be the first optimisation concept that fully integrates the 6Ps of people, product, process, partnership, profit, and place. The manufacturing initiative also achieves the goals of waste reduction, quality optimisation, inventory control, sale maximisation, optimised capacity utilisation, production viability, and production cost compression.

The proposed fit manufacturing model has shown that building industry leadership is not realised by focusing on achieving incremental improvements offered by lean and agile manufacturing. Incremental advantages such as cost squeezing, time to market reduction, increasing customer responsiveness (flexibility) and increasing the market share by additional point are capable of sustaining current business but do not create new ones. Sustainable profitable growth is achieved through evolution of competitive that ensures the organisation stays ahead of the competition and continuously excites customers. By combining the strengths of lean and agility with sustainability manufacturing firms can achieve fitness and long-term business perpetuation for economic gain. Simply focusing on lean and agile principles to meet all the requirements of today’s market conditions is insufficient to ensure long term economic survival. More relevant is how a manufacturing firm is able to re-invent itself time and time again; and build new competencies in order to remain fit and competitive for long-term.

Similarly, the integration of the business competitiveness and sustainability into one overall process is the core emphasis of fit manufacturing. The business goal for fit is to optimise each link in the business efficiency, effectiveness, and long-term sustainability by delivery value for customers and other stakeholders. Effectively building a dynamic and integrated manufacturing strategy that combines the strengths of leanness and agility with sustainability to deliver long-term fitness requires leveraging existing capabilities without introducing new lever of complexity into the manufacturing system. Such a shift is essential to ensure the continued competitiveness and survival of the manufacturing enterprise. Fit manufacturing offers a superior manufacturing model that leads to the development of fit enterprises capable of delivering sustainable benefits in an ever changing complex environment. Table 6.1 is an overview of manufacturing strategies describing how each manufacturing initiative handles key production enablers including sales, inventory, rejects, changeover time, installed capacity, and employee productivity. Table 6.2 is a summary of a comparative analysis of lean, agile and fit manufacturing approaches.

Other key findings of this research are:

- If Leanness Index (LI) = 0, then Fit Index (FI) = 0.

  This implies the attainment of leanness goals for any manufacturing company is considered as basic criteria that every company must operate just to remain ‘players’. This is due to that fact that most manufacturing systems conform to the basic principle of lean manufacturing

- Agile Index (AI) ≠ 0

  Within the concept of fit manufacturing, Agile Index (AI) can never assume a negative value or equal to zero because agility is an added-on condition on leanness. More so, a zero agile value signifies a manufacturing system that is unable to deliver value to the customer. This condition can only occur when the range of product mix available is less than 1

- If Sustainability Index (SI) = 0, then Fitness Index (FI) < 0

  This condition implies fitness can take on both positive and negative values. Negative values indicate the fitness level of the manufacturing company is in decline due to losses, and the cost of doing business being greater than profit. Positive values indicate the production system is able to maintain steady states or is in growth state beyond current boundaries.

- There is a strong associative relationship between economic sustainability and fitness, such that if a production system is not fit it cannot be sustainable, and if it not sustainable it cannot be fit

- Leanness Index (LI) ≠ Fitness Index (FI)

  Leanness is not equal to fitness though there is a proportionality relationship between leanness and fitness. Consequently, the implementation of leanness on its own in most industry may provide sufficient conditions to achieve long-term fitness. However, the focus on short-term goals of quality, waste reduction, time, and inventory management might not be sufficient to manage the enterprise long-term sustainability project.

- Over a period of time fitness curve takes the shape of “S Curve” when depicted graphically, and the operation of a manufacturing firm continually generates new fitness scores against which its long term economic sustainability is assessed.

- The slope of the fitness curve for a company indicates its degree of fitness and describes the rate at which the firm replicate successful outcomes. The degree of fitness is a measure of a firm's efficiency and fitness level. The most efficient firms usually achieve higher levels of degree of fitness, and are ranked first before other firms. A manufacturing firm's degree of fitness can also be used as a measure to optimise the firm's performance, and improve its fitness level.

Mass Production	Lean Production	Agile Production	Fit Manufacturing
Sales: viewed in terms of ROI	Sales: viewed in terms of profitability	Sales: viewed in terms of profitability	Sales: viewed in terms of profitability and fitness indicator
Inventory: treated as an asset	Inventory: treated as cost	Inventory: treated as cost	Inventory: treated as cost
Reject: treated as rework	Rejects: treated as waste to be eliminated or reduced	Rejects: treated as waste	Rejects: treated as waste and acts to penalise the production system
Changeover time: emphasis is on achieving set production targets	Changeover time: crucial in meeting JIT production criteria	Changeover time: crucial determining the system responsiveness	Changeover time: crucial in meeting JIT production criteria, system responsiveness, and also act to penalise the production system
Installed capacity: focus is on achieving economies of scale, and therefore, capacity holding is large – an extra cost to the business	Installed capacity: focus is on achieving flexibility, and JIT production.	Installed capacity: focus is on achieving flexibility in meeting product customisation	Installed capacity: focus is on achieving optimisation and dynamic utilisation, over-capacity is penalised
Employee productivity is measured in terms of sales revenue	Employee productivity is measured in terms of team performance	Employee productivity is measured in terms production system responsiveness	Employee productivity is measured as the ratio of total-paid-in to total-paid-out

Table 6.1: An overview of manufacturing strategies

Industry objectives	Lean Production System	Agile Production System	Fit Production System
Product market	A pull (Kanban) production system with emphasis on ensuring real customer demand *pull* product through the production system. Designed to serve high volume/low mix market.	A *push* production system designed to serve made-to-order market that requires short-lead time. The production system is suited to serve low volume/high mix market.	A *pull-push* integrated production system with flexible capability to switch between forecast demand and actual consumer demand production
Production system objective and orientation	A lean production system leveraging Kaizen to rapidly improve processes and drive results. Oriented towards repetitive manufacturing	An agile production system with ability to deliver flexibility at no additional cost. Oriented towards customisation manufacturing	An integrated production system that is lean, agile and sustainable with ability to handle full range of contingencies. Oriented towards integrated manufacturing
Skill level and cost	Requires very high level skills in waste elimination, inventory control, and value optimisation. Requires high capitalisation to achieve production system standardisation & stability (predictability)	Requires very high level skills in make-to-order capability. Requires high capitalization to handle variability in demand profile (achieve flexibility in production and assembly)	Requires cross-trained workers skilled in demand management, and capacity planning. Extend existing in-house manufacturing practices and initiative at no additional cost
Manufacturing approach	A multi-dimensional manufacturing approach that encompasses a wide variety of management practices to create a lean enterprise	A specialised manufacturing approach that is geared towards responsiveness to create an agile enterprise	A streamlined integrated manufacturing approach that synergistically create a fit enterprise

`Table 6.2: A summary of comparative analysis of lean, agile and fit manufacturing approaches

6.3. Suggestions for Future Work

This work has presented a framework for fit manufacturing and a model for fit production system. The fit manufacturing model presented in this work was validated using historical data from SMEs companies. Consequently, suggestions for future work include:

i. Application of the fit production model to medium sized, and large sized companies including multinationals

ii. Further work is required on the investigation and analysis of the relationship between fitness and agility.

iii. Further work is required on the development of sustainability index, and degree of fitness both of which can be used as ranking, and predictive modelling tools to analyse and evaluating long-term fitness of manufacturing firms

iv. Development of a statistical package for automatic production data collection and analysis. Such a tool will be effective in managing both daily and long-term fitness levels of a manufacturing firm

v. Future work can also consider establishing sufficient conditions for fitness. This will be useful to describe in complete terms the conditions manufacturing firms need to attain and maintain for long-term sustainability and fitness.

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Appendix A

Table 4A: Ballpoint Pen Quality Inspection

Pen	Length	Diameter	Surface Coating	Viscosity Checks	Colour	Defective	No of defects per pen
Pen #1			X	X	X	Yes	3
Pen #2	X					Yes	1
Pen #3		X	X	X	X	Yes	4
Pen #4						No	0
Pen #5						No	0
Pen #6		X	X			Yes	2
Pen #7			X			Yes	1
Pen #8	X	X	X	X		Yes	4
Pen #9						No	0
Pen #10	X	X				Yes	2

Appendix B

Appendix B-1a: Summary of Case Study Companies Production Characteristics (Ebrahim, 2011)

Characteristics	**Manufacturing companies**					
	A	**B**	**C**	**D**	**E**	**F**
Input classification	Single	Single	Multiple	Multiple	Single	Multiple
Output classification	Multiple	Single	Multiple	Multiple	Single	Multiple
Production Operations based	Technology intensive	Technology intensive	Labour Intensive	Technology intensive	Labour Intensive	Technology intensive
Level of automation process	Semi-auto	Semi-auto	Manual	Semi-auto	Manual	Semi-auto
Order fulfilment based	MTO	MTS (majority) MTO	MTS (majority) MTO	MTO (majority) MTS	MTO	MTS
Standard operating hours (per day)	24 hours (two shifts)	8 hours (Mon-Fri) 5 hours (Sat.)	8 hours (Mon-Fri) 5 hours (Sat.)	8 hours (Mon-Fri) 5 hours (Sat.)	8 hours (Mon-Fri)	8 hours (Mon-Fri) 5 hours (Sat.)
Design/specification changes based	Customer-oriented (customisation)	Self-oriented (innovation)	Self-oriented (innovation)	Market-oriented (competition)	Self-oriented (innovation)	Self-oriented (innovation)

Appendix B-2a: Sample Leanness Index Calculation

Company A: 2005

Month	Input quantity (ton)	Paid-out cost	Inventory (ton)	Paid-out cost	Scrap (ton)	Paid-out cost	Returned (ton)	Paid-out cost	Rejects (ton) = Scrap + Returned	Paid-out cost (Rejects)	Sales	Paid-in cost	Leanness Index (LI)
Jan	18.09	91,174	4.93	24,847	0.83	4,017	0.01	50	**0.84**	**4,067**	22.08	187,680	1.58
Feb	18.09	90,812	2.49	12,500	1.17	5,639	0.26	1,305	**1.43**	**6,944**	19.36	164,560	1.53
March	20.10	100,098	1.22	6,076	0.09	446	0.18	896	**0.27**	**1,342**	21.28	180,880	1.69
April	20.10	100,701	0.99	4,960	0.07	337	0.02	100	**0.09**	**437**	20.26	172,210	1.63
May	20.77	103,850	0.73	3,650	0.16	797	0.11	550	**0.27**	**1,347**	20.92	177,820	1.64
June	20.77	103,642	0.00	0	0.60	2,874	0.01	50	**0.61**	**2,924**	21.02	178,670	1.70
July	22.12	109,936	0.56	2,783	0.44	2,099	0.03	149	**0.47**	**2,248**	19.03	161,755	1.42
Aug	21.44	106,771	0.38	1,892	0.25	1,195	0.55	2,739	**0.80**	**3,934**	20.04	170,340	1.53
Sept	21.44	106,771	0.40	1,992	0.59	2,820	0.04	199	**0.63**	**3,019**	19.49	165,665	1.50
Oct	22.12	109,936	0.44	2,187	0.77	3,673	0.22	1,093	**0.99**	**4,766**	18.27	155,295	1.34
Nov	19.43	97,150	0.88	4,400	0.29	1,392	0.25	1,250	**0.54**	**2,642**	19.33	164,305	1.59
Dec	21.44	106,771	0.00	0	0.44	2,103	0.08	398	**0.52**	**2,501**	21.62	183,770	1.70
Total	**245.91**	**1,227,612**	**13.02**	**65,287**	**5.70**	**27,392**	**1.76**	**8,779**	**7.46**	**36,171**	**242.70**	**2,062,950**	**1.57**

Appendix B-2b: Sample Agility Index Calculation

COMPANY A: 2005

Month	Size of product variety	Size of Volume Variety	Total Changeover period (day)	Total Changeover period (hrs)	Agility Index (AI)
Jan	2.49	5.00	0.83	19.92	0.38
Feb			0.75	18.00	0.42
March			0.81	19.44	0.39
April			0.81	19.44	0.39
May			0.83	19.92	0.38
June			0.81	19.44	0.39
July			0.83	19.92	0.38
Aug			0.81	19.44	0.39
Sept			0.81	19.44	0.39
Oct			0.83	19.92	0.38
Nov			0.75	18.00	0.42
Dec			0.83	19.92	0.38
Total			9.70	232.80	**4.64**

Appendix B-2c: Sample Sustainability Index Calculation

COMPANY A: 2005

Month	Installed Capacity (RM)											Production: Labour Cost (RM)						Revenue (RM)		Economic Sustainability Index (ESI)
	Maximum Available Input Quantity (ton)	Paid-out cost	Actual Input quantity (ton)	Paid-out cost	Inventory (ton)	Paid-out cost	Scrap (ton)	Paid-out cost	Returned (ton)	Paid-out cost	Material Paid-out Cost	Production Period (day)	Production Period (hour)	Paid-out cost @ rate of RM5/hr for Senior(1) & RM3 for Trainee(3)	Overtime Period (hour) *Flat rate of RM15/hr x Total no of overtime hrs*	Paid-out cost (Overtime x15)	Total Labour Cost	Sales	Paid-in cost	
Jan	20.80	104,832	18.09	91,174	4.93	24,847	0.83	4,017	0.01	50	**120,088**	30.11	722.64	10,117	50.64	759.60	**10,877**	22.08	187,680	1.25
Feb	18.70	94,248	18.09	90,812	2.49	12,500	1.17	5,639	0.26	1,305	**110,256**	26.23	629.52	8,813	29.52	442.80	**9,256**	19.36	164,560	1.33
March	20.80	104,832	20.10	100,098	1.22	6,076	0.09	446	0.18	896	**107,516**	29.14	699.36	9,791	0.00	0.00	**9,791**	21.28	180,880	1.47
April	20.10	101,304	20.10	100,701	0.99	4,960	0.07	337	0.02	100	**106,098**	29.14	699.36	9,791	27.36	410.40	**10,201**	20.26	172,210	1.47
May	20.80	104,832	20.77	103,850	0.73	3,650	0.16	797	0.11	550	**108,847**	30.11	722.64	10,117	26.64	399.60	**10,517**	20.92	177,820	1.48
June	20.10	101,304	20.77	103,642	0.00	0	0.60	2,874	0.01	50	**106,566**	29.14	699.36	9,791	3.36	50.40	**9,841**	21.02	178,670	1.57
July	20.80	104,832	22.12	109,936	0.56	2,783	0.44	2,099	0.03	149	**114,967**	30.11	722.64	10,117	0.00	0.00	**10,117**	19.03	161,755	1.36
Aug	20.80	104,832	21.44	106,771	0.38	1,892	0.25	1,195	0.55	2,739	**112,597**	29.14	699.36	9,791	0.00	0.00	**9,791**	20.04	170,340	1.42
Sept	20.10	101,304	21.44	106,771	0.40	1,992	0.59	2,820	0.04	199	**111,782**	29.14	699.36	9,791	0.00	0.00	**9,791**	19.49	165,665	1.44
Oct	20.80	104,832	22.12	109,936	0.44	2,187	0.77	3,673	0.22	1,093	**116,889**	30.11	722.64	10,117	0.00	0.00	**10,117**	18.27	155,295	1.28
Nov	20.10	101,304	19.43	97,150	0.88	4,400	0.29	1,392	0.25	1,250	**104,192**	26.23	629.52	8,813	0.00	0.00	**8,813**	19.33	164,305	1.39
Dec	20.80	104,832	21.44	106,771	0.00	0	0.44	2,103	0.08	398	**109,272**	30.11	722.64	10,117	2.64	39.60	**10,157**	21.62	183,770	1.57
Total	**244.70**	**1,233,288**	**245.91**	**1,227,612**	**13.02**	**65,287**	**5.70**	**27,392**	**1.76**	**8,779**	**1,329,070**	**348.71**	**8369.04**	**117,167**	**140.16**	**2102.40**	**119,269**	**242.70**	**2,062,950**	**1.42**

Category	2005	2006	2007	2008	2009
Senior Operator (more than three years working experience = min. RM5.00 per hour	1	1	1	1	2
Junior Operator (one to two years working experience) = min. RM4.00 per hour		1	1	1	
Training Operator (less than one year working experience) = RM3.00 per hour	3	2	2	2	2
Total no. of operators	**4**	**4**	**4**	**4**	**4**
Overtime rate:is usually at double rate. Howvere, figure of operator elements not available, assumed a flat rate of RM:15					

Appendix B-2d: Sample Production Fitness Index Calculation

COMPANY A

Month	Production Fitness																			
	2005				2006				2007				2008				2009			
	Leanness Index	Agility Index	Economic Sustainabilty Index	Production Fitness Index	Leanness Index	Agility Index	Economic Sustainabilty Index	Production Fitness Index	Leanness Index	Agility Index	Economic Sustainabilty Index	Production Fitness Index	Leanness Index	Agility Index	Economic Sustainabilty Index	Production Fitness Index	Leanness Index	Agility Index	Economic Sustainabilty Index	Production Fitness Index
Jan	1.58	0.38	1.25	0.74	1.58	0.40	1.33	0.83	1.52	0.47	0.79	0.56	1.51	0.35	1.47	0.77	1.25	0.40	0.96	0.48
Feb	1.53	0.42	1.33	0.84	1.72	0.40	1.53	1.04	1.01	0.39	0.86	0.33	1.34	0.37	1.30	0.64	1.22	0.37	1.23	0.55
March	1.69	0.39	1.47	0.96	1.52	0.38	1.37	0.78	1.62	0.36	1.36	0.79	1.46	0.34	1.48	0.74	1.36	0.35	1.34	0.63
April	1.63	0.39	1.47	0.92	1.51	0.39	1.37	0.80	1.68	0.36	1.48	0.89	1.41	0.35	1.43	0.70	1.36	0.35	1.35	0.65
May	1.64	0.38	1.48	0.91	1.40	0.38	1.28	0.68	1.68	0.35	1.63	0.95	1.53	0.34	1.55	0.81	1.36	0.34	1.40	0.65
June	1.70	0.39	1.57	1.03	1.31	0.39	1.21	0.61	1.48	0.35	1.44	0.75	1.62	0.35	1.63	0.91	1.34	0.35	1.32	0.63
July	1.42	0.38	1.36	0.72	1.76	0.38	1.59	1.05	1.50	0.35	1.46	0.76	1.41	0.34	1.42	0.69	1.60	0.40	1.21	0.78
Aug	1.53	0.39	1.42	0.84	1.65	0.38	1.50	0.93	1.86	0.35	1.80	1.16	1.45	0.34	1.46	0.73	1.22	0.35	1.20	0.51
Sept	1.50	0.39	1.44	0.83	1.53	0.39	1.40	0.83	1.54	0.35	1.50	0.82	1.47	0.35	1.48	0.75	1.23	0.35	1.27	0.54
Oct	1.34	0.38	1.28	0.65	1.92	0.42	1.53	1.22	1.46	0.36	1.33	0.70	1.50	0.36	1.37	0.75	1.62	0.36	1.52	0.89
Nov	1.59	0.42	1.39	0.92	1.55	0.41	1.32	0.83	1.53	0.35	1.50	0.81	1.49	0.35	1.51	0.78	1.54	0.35	1.54	0.84
Dec	1.70	0.38	1.57	1.00	1.57	0.53	0.85	0.70	1.55	0.35	1.51	0.81	1.43	0.34	1.46	0.72	1.23	0.34	1.27	0.54
Ave.	1.57	0.39	1.42	0.86	1.59	0.40	1.36	0.86	1.54	0.37	1.39	0.78	1.47	0.35	1.46	0.75	1.36	0.36	1.30	0.64

Appendix C

Appendix C-1: Summary of Company A's Agility Index, Leanness Index, Sustainability Index, and Overall Production Fitness Index

Month	Agility	Agility	Company A - Agility Index (AI)	Company A - Leanness Index (LI)	Company A - Sustainability Index (ESI)	Company A - OPFI
	Product Size	**Volume Size**				
2005: Month 1	2.49	5.00	0.38	1.58	1.25	0.74
2			0.42	1.53	1.33	0.84
3			0.39	1.69	1.47	0.96
4			0.39	1.63	1.47	0.92
5			0.38	1.64	1.48	0.91
6			0.39	1.70	1.57	1.03
7			0.38	1.42	1.36	0.72
8			0.39	1.53	1.42	0.84
9			0.39	1.50	1.44	0.83
10			0.38	1.34	1.28	0.65
11			0.42	1.59	1.39	0.92
12			0.38	1.70	1.57	1.00
2006: Jan	2.49	5.00	0.40	1.58	1.33	0.83
14			0.40	1.72	1.53	1.04
15			0.38	1.52	1.37	0.78
16			0.39	1.41	1.37	0.80
17			0.38	1.40	1.28	0.68
18			0.39	1.31	1.21	0.61
19			0.38	1.76	1.59	1.05
20			0.38	1.65	1.50	0.93
21			0.39	1.53	1.40	0.83
22			0.42	1.92	1.53	**1.22**
23			0.41	1.55	1.32	0.83
24			0.53	1.57	0.85	0.70
2007: Jan	3.15	5.00	0.47	1.52	0.79	0.56
26			0.39	1.01	0.86	0.33
27			0.36	1.62	1.36	0.79
28			0.36	1.68	1.48	0.89
29			0.35	1.68	1.63	0.95
30			0.35	1.48	1.44	0.75
31			0.35	1.50	1.46	0.76
32			0.35	1.86	1.80	1.16
33			0.35	1.54	1.50	0.82
34			0.35	1.46	1.33	0.70
35			0.35	1.53	1.50	0.81
36			0.35	1.55	1.51	0.81
2008: Jan	3.15	5.00	0.35	1.51	1.47	0.77
38			0.37	1.34	1.30	0.64
39			0.34	1.46	1.48	0.74
40			0.35	1.41	1.43	0.70
41			0.34	1.53	1.55	0.81
42			0.35	1.62	1.63	0.91
43			0.34	1.41	1.42	0.69
44			0.34	1.45	1.46	0.73
45			0.35	1.47	1.48	0.75
46			0.36	1.50	1.37	0.75
47			0.35	1.49	1.51	0.78
48			0.34	1.43	1.46	0.72
2009:Jan	3.15	5.00	0.40	1.25	0.96	0.48
50			0.37	1.22	1.23	0.55
51			0.35	1.36	1.34	0.63
52			0.35	1.36	1.35	0.65
53			0.34	1.36	1.40	0.65
54			0.35	1.34	1.2	0.63
55			0.40	1.60	1.21	0.78
56			0.35	1.22	1.20	0.51
57			0.35	1.23	1.27	0.54
58			0.36	1.62	1.52	0.89
59			0.35	1.54	1.54	0.84
60			0.34	1.23	1.27	0.54

Appendix C-2: Summary of Company B's Agility Index, Leanness Index, Sustainability Index, and Overall Production Fitness Index

Month	Agility	Agility	Company B - Agility Index (AI)	Company B - Leanness Index (LI)	Company B - Sustainability Index (ESI)	Company B - OPFI
	Product Size	Volume Size				
2005: Month 1	2.16	6.50	N/A	5.46	2.89	N/A
2			N/A	4.92	2.18	N/A
3			N/A	6.61	4.90	N/A
4			N/A	5.01	2.04	N/A
5			N/A	5.38	3.07	N/A
6			N/A	5.41	2.86	N/A
7			N/A	5.32	1.88	N/A
8			N/A	6.02	3.22	N/A
9			N/A	6.40	5.28	N/A
10			N/A	5.66	2.79	N/A
11			N/A	5.61	3.50	N/A
12			N/A	1.42	1.73	N/A
2006: Jan	2.16	6.50	N/A	3.84	1.17	N/A
14			N/A	1.49	2.31	N/A
15			N/A	5.55	4.98	N/A
16			N/A	4.42	3.17	N/A
17			N/A	4.15	1.97	N/A
18			N/A	2.59	1.06	N/A
19			N/A	1.84	1.14	N/A
20			N/A	7.45	0.00	N/A
21			1.24	6.15	4.00	30.45
22			8.66	4.17	0.94	34.15
23			2.17	2.29	1.03	5.13
24			8.66	1.45	0.31	3.94
2007: Jan	2.16	6.50	4.33	4.20	0.91	16.65
26			2.89	5.18	1.96	29.33
27			1.44	6.59	4.28	40.73
28			2.17	3.46	1.84	13.80
29			2.17	3.28	1.64	11.66
30			8.66	5.86	1.37	69.72
31			4.33	4.38	1.06	20.07
32			8.66	4.93	1.16	49.32
33			1.08	5.12	4.69	26.00
34			4.33	2.68	1.26	14.58
35			2.89	2.85	1.18	9.72
36			8.66	2.09	1.05	19.05
2008: Jan	2.16	6.50	1.73	5.58	3.29	31.78
38	2.99	8.50	3.83	4.01	1.91	29.34
39	3.32	8.50	1.31	4.86	4.74	30.12
40			2.36	3.68	1.93	16.79
41			1.97	3.70	2.07	15.10
42			1.31	6.09	5.12	40.88
43			1.31	4.66	3.05	18.67
44			1.31	4.67	3.42	20.99
45			0.84	5.35	5.87	26.51
46			0.79	4.16	5.50	18.00
47			1.07	4.23	4.15	18.87
48			1.79	6.31	4.84	54.66
2009:Jan	2.32	8.50	0.98	4.58	4.03	18.17
50			1.20	3.01	2.47	8.94
51			0.90	4.81	5.86	25.41
52			0.83	2.79	3.14	7.29
53			1.55	3.47	2.30	12.35
54			0.98	4.80	5.46	25.80
55			1.08	4.40	3.35	15.94
56			1.20	3.79	3.23	14.71
57			0.90	4.80	8.08	34.94
58			0.68	3.95	4.78	12.78
59			1.20	3.77	4.32	19.59
60			0.90	4.54	5.31	21.74

Appendix C-3: Summary of Company C’s Agility Index, Leanness Index, Sustainability Index, and Overall Production Fitness Index

Month	Agility	Agility	Company C - Agility Index (AI)	Company C - Leanness Index (LI)	Company C - Sustainability Index (ESI)	Company C - OPFI
	Product Size	Volume Size				
2005: Month 1	3.32	3.00	N/A	1.90	0.57	N/A
2			N/A	1.59	0.58	N/A
3			N/A	1.88	0.60	N/A
4			N/A	2.66	1.11	N/A
5			N/A	2.27	0.69	N/A
6			N/A	2.41	0.62	N/A
7			N/A	2.28	0.69	N/A
8			N/A	2.37	0.82	N/A
9			N/A	2.92	1.04	N/A
10			N/A	2.86	1.00	N/A
11			N/A	1.94	0.51	N/A
12			N/A	1.77	0.65	N/A
2006: Jan	3.32	3.00	N/A	1.13	0.36	N/A
14			N/A	1.98	0.75	N/A
15			N/A	1.27	0.54	N/A
16			N/A	1.28	0.66	N/A
17			N/A	1.97	0.87	N/A
18			N/A	1.63	0.60	N/A
19			N/A	2.16	0.79	N/A
20			N/A	2.19	0.69	N/A
21			N/A	1.83	0.69	N/A
22			N/A	2.95	0.59	N/A
23			N/A	3.18	0.76	N/A
24			N/A	N/A	N/A	N/A
2007: Jan	0.00	0.00	N/A	1.35	0.44	N/A
26	0.00	0.00	N/A	1.90	0.59	N/A
27	0.00	0.00	N/A	1.94	0.61	N/A
28	3.32	3.00	0.82	1.58	0.67	0.87
29			0.66	2.40	1.01	1.59
30			0.82	2.53	0.84	1.74
31			0.66	3.04	0.91	1.83
32			0.82	2.46	0.74	1.49
33			0.66	2.92	1.28	2.45
34			0.82	1.60	0.56	0.74
35			N/A	2.54	0.91	N/A
36			N/A	2.46	1.03	N/A
2008: Jan	0.00	0.00	N/A	1.52	0.28	N/A
38	0.00	0.00	N/A	1.68	0.35	N/A
39	0.00	0.00	N/A	1.83	0.39	N/A
40	0.00	0.00	N/A	1.63	0.38	N/A
41	3.32	3.00	0.82	1.47	0.49	0.59
42			0.82	1.73	0.57	0.81
43			0.82	1.87	0.61	0.94
44			0.82	1.99	0.48	0.79
45			0.82	1.84	0.85	1.29
46			N/A	2.17	0.55	N/A
47			N/A	2.13	0.73	N/A
48			N/A	2.04	0.70	N/A
2009:Jan	0.00	0.00	N/A	1.96	0.73	N/A
50	0.00	0.00	N/A	2.09	0.67	N/A
51	0.00	0.00	N/A	2.28	1.03	N/A
52	3.65	3.65	0.47	2.16	0.96	0.96
53			1.86	2.19	0.70	2.86
54			0.93	1.83	0.47	0.80
55			1.86	2.20	0.64	2.61
56			1.86	2.35	0.68	**2.99**
57			0.93	1.88	0.57	1.00
58	0.00	0.00	1.86	1.78	0.55	1.82
59			N/A	2.22	0.84	N/A
60			N/A	0.48	0.21	N/A

Appendix C-4: Summary of Company D's Agility Index, Leanness Index, Sustainability Index, and Overall Production Fitness Index

Month	**Agility**	**Agility**	**Company D - Agility Index (AI)**	**Company D - Leanness Index (LI)**	**Company D - Sustainability Index (ESI)**	**Company D - OPFI**
	Product Size	**Volume Size**				
2005: Month 1			N/A	N/A	N/A	N/A
2			N/A	N/A	N/A	N/A
3			N/A	N/A	N/A	N/A
4			N/A	N/A	N/A	N/A
5			N/A	N/A	N/A	N/A
6			N/A	N/A	N/A	N/A
7			N/A	N/A	N/A	N/A
8			N/A	N/A	N/A	N/A
9			N/A	N/A	N/A	N/A
10			N/A	N/A	N/A	N/A
11			N/A	N/A	N/A	N/A
12			N/A	N/A	N/A	N/A
2006: Jan			N/A	1.83	0.14	0.26
14			N/A	1.71	0.07	0.13
15			N/A	1.36	0.08	0.11
16			N/A	1.35	0.11	0.21
17			N/A	1.54	0.06	0.10
18			N/A	1.32	0.16	0.30
19			N/A	1.48	0.07	0.11
20			N/A	**1.72**	0.07	**0.13**
21			N/A	2.32	0.10	0.24
22			N/A	1.27	0.13	0.17
23			N/A	1.34	0.07	0.10
24			N/A	1.70	0.12	0.20
2007: Jan			N/A	1.70	0.15	0.26
26			N/A	1.47	0.14	0.21
27			N/A	1.28	0.13	0.16
28			N/A	1.73	0.16	0.28
29			N/A	1.48	0.14	0.20
30			N/A	1.46	0.14	0.20
31			N/A	1.41	0.14	0.19
32			N/A	2.14	0.17	**0.36**
33			N/A	1.25	0.13	0.16
34			N/A	1.43	0.15	0.21
35			N/A	1.17	0.11	0.13
36			N/A	1.81	0.17	0.30
2008: Jan			N/A	2.73	0.02	0.07
38			N/A	2.44	0.03	0.09
39			N/A	1.70	0.03	0.06
40			N/A	2.21	0.05	0.12
41			N/A	2.00	0.05	0.09
42			N/A	1.82	0.05	0.09
43			N/A	2.63	0.06	0.15
44			N/A	2.38	0.07	0.16
45			N/A	1.83	0.04	0.07
46			N/A	1.99	0.06	0.12
47			N/A	2.02	0.05	0.09
48			N/A	1.99	0.07	0.15
2009:Jan			N/A	1.92	0.16	0.30
50			N/A	2.02	0.17	0.33
51			N/A	1.82	0.13	0.23
52			N/A	2.07	0.16	0.34
53			N/A	1.91	0.14	0.27
54			N/A	1.87	0.19	0.35
55			N/A	1.79	0.13	0.23
56			N/A	2.20	0.16	**0.36**
57			N/A	1.72	0.09	0.15
58			N/A	1.84	0.12	0.22
59			N/A	1.66	0.09	0.16
60			N/A	1.73	0.16	0.29

Appendix C-5: Summary of Company E's Agility Index, Leanness Index, Sustainability Index, and Overall Production Fitness Index

Month	Agility	Agility	Company E - Agility Index (AI)	Company E - Leanness Index (LI)	Company E - Sustainability Index (ESI)	Company E - OPFI
	Product Size	**Volume Size**				
2005: Month 1	Data Not Available	Data Not Available	N/A	N/A	N/A	N/A
2			N/A	N/A	N/A	N/A
3			N/A	N/A	N/A	N/A
4			N/A	N/A	N/A	N/A
5			N/A	N/A	N/A	N/A
6			N/A	N/A	N/A	N/A
7			N/A	N/A	N/A	N/A
8			N/A	N/A	N/A	N/A
9			N/A	N/A	N/A	N/A
10			N/A	N/A	N/A	N/A
11			N/A	N/A	N/A	N/A
12			N/A	N/A	N/A	N/A
2006: Jan	Data Not Available	Data Not Available	N/A	1.08	0.20	0.21
14			N/A	2.23	0.48	1.07
15			N/A	0.55	0.11	0.06
16			N/A	2.07	0.40	0.82
17			N/A	0.67	0.15	0.10
18			N/A	0.45	0.09	0.04
19			N/A	0.41	0.09	0.04
20			N/A	0.80	0.15	0.12
21			N/A	1.42	0.26	0.37
22			N/A	1.98	0.41	0.81
23			N/A	1.20	0.20	0.24
24			N/A	0.87	0.19	0.17
2007: Jan			N/A	0.64	0.14	0.09
26	Data Not Available	Data Not Available	N/A	0.64	0.16	0.10
27			N/A	0.66	0.14	0.09
28			N/A	0.00	0.00	0.00
29			N/A	0.99	0.18	0.18
30			N/A	0.00	0.00	0.00
31			N/A	0.17	0.05	0.01
32			N/A	1.69	0.30	0.51
33			N/A	1.20	0.26	0.31
34			N/A	0.57	0.14	0.08
35			N/A	0.56	0.12	0.07
36			N/A	0.90	0.22	0.20
2008: Jan			N/A	1.12	0.22	0.25
38	Data Not Available	Data Not Available	N/A	0.42	0.11	0.04
39			N/A	1.42	0.00	0.00
40			N/A	0.00	0.00	0.00
41			N/A	0.49	0.11	0.05
42			N/A	0.35	0.07	0.02
43			N/A	0.97	0.17	0.16
44			N/A	0.62	0.12	0.07
45			N/A	0.88	0.14	0.12
46			N/A	0.00	0.00	0.00
47			N/A	0.00	0.00	0.00
48			N/A	0.96	0.17	0.17
2009:Jan			N/A	0.22	0.06	0.01
50	Data Not Available	Data Not Available	N/A	0.60	0.10	0.06
51			N/A	0.00	0.00	0.00
52			N/A	0.71	0.12	0.08
53			N/A	0.00	0.00	0.00
54			N/A	0.00	0.00	0.00
55			N/A	1.03	0.17	0.18
56			N/A	2.73	0.41	**1.11**
57			N/A	1.99	0.28	0.55
58			N/A	0.74	0.11	0.08
59			N/A	1.31	0.19	0.24
60			N/A	1.25	0.17	0.21

Appendix C-6: Summary of Company F's Agility Index, Leanness Index, Sustainability Index, and Overall Production Fitness Index

Month	Agility	Agility	Company F - Agility Index (AI)	Company F - Leanness Index (LI)	Company F - Sustainability Index (ESI)	Company F - OPFI
	Product Size	**Volume Size**				
2005: Month 1	Data Not Available	Data Not Available	N/A	N/A	N/A	N/A
2			N/A	N/A	N/A	N/A
3			N/A	N/A	N/A	N/A
4			N/A	N/A	N/A	N/A
5			N/A	N/A	N/A	N/A
6			N/A	N/A	N/A	N/A
7			N/A	N/A	N/A	N/A
8			N/A	N/A	N/A	N/A
9			N/A	N/A	N/A	N/A
10			N/A	N/A	N/A	N/A
11			N/A	N/A	N/A	N/A
12			N/A	N/A	N/A	N/A
2006: Jan	Data Not Available	Data Not Available	N/A	N/A	N/A	N/A
14			N/A	N/A	N/A	N/A
15			N/A	N/A	N/A	N/A
16			N/A	N/A	N/A	N/A
17			N/A	N/A	N/A	N/A
18			N/A	N/A	N/A	N/A
19			N/A	N/A	N/A	N/A
20			N/A	N/A	N/A	N/A
21			N/A	N/A	N/A	N/A
22			N/A	N/A	N/A	N/A
23			N/A	N/A	N/A	N/A
24			N/A	N/A	N/A	N/A
2007: Jan			N/A	N/A	N/A	N/A
26	Data Not Available	Data Not Available	N/A	N/A	N/A	N/A
27			N/A	N/A	N/A	N/A
28			N/A	N/A	N/A	N/A
29			N/A	N/A	N/A	N/A
30			N/A	N/A	N/A	N/A
31			N/A	3.12	1.78	5.55
32			N/A	4.13	2.88	11.91
33			N/A	4.22	2.92	12.32
34			N/A	4.52	3.11	14.09
35			N/A	4.33	2.98	12.93
36			N/A	4.06	3.49	14.20
2008: Jan			N/A	3.59	2.69	9.64
38	Data Not Available	Data Not Available	N/A	3.76	3.10	11.65
39			N/A	3.52	3.23	11.40
40			N/A	3.38	3.45	11.68
41			N/A	3.76	1.81	6.82
42			N/A	3.92	2.18	8.57
43			N/A	3.55	1.57	5.56
44			N/A	3.41	1.94	6.61
45			N/A	3.83	2.56	3.80
46			N/A	3.94	3.64	14.36
47			N/A	3.35	2.17	7.28
48			N/A	3.87	3.57	13.82
2009:Jan			N/A	3.76	3.50	13.15
50	Data Not Available	Data Not Available	N/A	3.77	3.12	11.78
51			N/A	3.90	4.41	**17.17**
52			N/A	3.93	3.17	12.45
53			N/A	3.83	3.09	11.82
54			N/A	3.94	4.16	16.39
55			N/A	3.66	2.00	7.32
56			N/A	**3.68**	2.26	8.32
57			N/A	3.30	1.42	4.69
58			N/A	3.67	2.01	7.40
59			N/A	3.59	1.78	6.37
60			N/A	3.50	1.95	6.83