



Application of Lean and Agile Manufacturing Process in New Product Development.

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By

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ABSTRACT

As technology evolves globally, it becomes difficult for a single production improvement tool to support the maximum productivity, flexibility, and competitiveness necessary for a firm to continuously increase its value chain to fulfill customer-changing requirements. The global market of today continues to be more competitive and the demand for highly functional products, high-quality service, shorter delivery lead-time, and environmental friendliness continues to grow to fit customers' changing demand requirements. This research focused on tackling the problem of underperformance of a firm's products that cannot be properly covered by a single productivity improvement process such as lean or Agile. The unsatisfactory factor of using either lean or agile makes it difficult for a firm to continuously increase its productivity, flexibility, and competitiveness to support a firm ability to fit values that satisfy customer-changing requirements in both stable and turbulent market environments. The research study focused on the successful integration of lean and agile manufacturing processes in new product development to improve productivity, flexibility, and competitiveness to fit customer-changing requirements in a global market environment. Moreover, the effect of disturbances such as new entrants, technological evolution, globalization, and customer-changing requirements deprives a single tool such as lean or agile the ability to satisfy changing customer requirements. This effect of technological evolution, globalization, etc., has led to redundancy, obsolescence, abandonment, and extinction which creates financial losses for firms. This research utilized synergies (robustness and smartification) of lean and agile tools to improve new products to fit customer-changing requirements in stable and turbulent market environments. The study used Taguchi's design of experiment to determine productivity differences in using a single tool of lean or single tool of agile or a combined tool of lean and agile in the management of new product development. The study performance outcome in terms of process performance (CP & CPK), Performance distribution, waste variation reduction, and loss function financial evaluation revealed that using a combination of lean and agile performed significantly best than using either a single tool of lean or a single tool of Agile. The study used the Taguchi design of the experiment to support a robust improvement integration process. The result showed that the integration of lean and agile methodology offers better efficiency and effectiveness than using either a single lean or agile methodology. The study concluded that using a combination of lean and agile tools improves the underperformance of new product development to fit customer market-changing requirements compared to using either a single lean tool or agile tool alone.

DECLARATION

I, Gregory I. Ezeani declare that; (i) The research reported in this thesis, except where otherwise indicated, is my original work. (ii) This thesis has not been submitted for any degree or examination at any other university. (iii) This thesis does not contain other persons' data, pictures, graphs, or other information unless specifically acknowledged as being sourced from other persons. (iv) This thesis does not contain other persons' writing unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then: a) their words have been re-written but the general information attributed to them has been referenced; b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced. (v) This thesis does not contain text, graphics, or tables copied and pasted from the Internet, unless specifically acknowledged, and the source is detailed in the thesis and in the References sections.

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DEDICATION

I dedicated this Doctor of Engineering dissertation to all my family members and friends who have supported and encouraged me throughout this journey. Your support on different forms has played a crucial role in my success. I remain forever grateful for all your great support, which made this dissertation completion possible. I am grateful for all your wonderful prayers and encouragement, which continue to strengthen me so that the inevitable effect of fatigue never stop me from completing this work.

Finally, I dedicate this dissertation to both my late father and late elder senior brother, who passed away before they could see me reach the milestone. May your souls rest in perfect peace in the lord's house. I also dedicated this work to my mother whom I love so much but the stress of this journey deprived me of a constant son communication relationship with her, regardless of those constraints she continues to pray for me to succeed in completing this dissertation. I am sorry for all the pain I caused you because of my quest to complete a Doctor of Industrial Engineering degree.

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INTRODUCTION

Overview

The global market environment of today continues to change as new entrants increase competitiveness and adopt new product customization strategies that fit customer-changing requirements using the innovation of new values during new product development. The struggle among firms to increase market share, reduce obsolescence, and reduce redundancy which continues to become more relevant as extinction traits continue to loom among firms in the global market environment. The market environment of today continues to be unsteady as technology evolves which continues to cause new products to underperform in satisfying customer-changing requirements. The trait of globalization and technological advancement has led to high volume product customization that creates high market turbulence that causes continuous market disruption that impacts most manufacturing/production firms' adaptability in managing obsolescence and redundancy. The gap that exists in this study with other studies is that there is no existing structured methodology to this date on how to apply both lean and agile as a single tool in manufacturing processes during new product development. The integration of lean and agile will reduce both total cycle time and total lead time waste which will help to manage underperformance of new product to fits customer changing requirement. Moreover, the problem of adaptability continues to be among the leading causes of underperformance and extinction of most firms due to their inability to manage waste that results from non-value creation activity that limits firm sustainability strategies. Perhaps, the global market of today consistently continues to experience competition as customer needs to continue to focus on the demand for high-functional products, high-quality service, shorter delivery lead times, and increased environmental friendliness products that fit today's value needs. The need for rapid consistent responsive value creation continues to be an inevitable survival requirement for every firm to avoid the trait of extinction during new product development that will fit customer-changing requirements in a global marketplace. Moreover, the nature and structure of the value that a firm creates to satisfy its customer's needs reveal its robustness and preparedness to withstand disturbances that impact its market environment, and it also discloses its smartification strength to respond effectively to fit customer-changing requirements. The presence of globalization and technological evolvement has continued to create customization in value creation to fit customer-changing requirements tremendously as new emerging markets are liberated. Therefore, today's manufacturing/production strategies continue to

stand the biggest challenges towards defining a lean and agile methodology to manage both a stable and a turbulent market environment satisfactorily to correct the underperformance of products to fit customer-changing requirements.

1.1 Background of the Study

The research originates its study from a superior understanding of the major causes of the underperformance of products in the modern global market of today which have led to productivity losses that continue to be the leading cause of extinction struggle of most firms to support their sustainability strategies. The study was able to reveal that the unsatisfactory performance of products to fit customer-changing requirements was caused by the effect of evolving technology and globalization which creates variation in different market environments. The impact of globalization and technological evolvment has created an inevitable need to improve the production management system of today to fit customer-changing requirements so it will alleviate many firms from the trait of redundancy, obsolescence, and extinction that currently results from underperformance. The global market environment of today continues to task industrial engineers on the need to improve the underperformance of products during new product process development which will help to reduce waste of all forms and add value incrementally to new products to satisfy customer changing requirements regardless of the market environment. The previous studies also found that a single production tool of lean or Agile is not capable enough to withstand the dynamics of technological evolvment and globalization in managing steady and unsteady customer-changing requirements in different market environments at different times to generate significant profit for firms. The global market of today requires an industrial engineer to develop new products that will use the synergy of both lean and agile to offer new product quality of robustness and smartness features so that it can adapt or withstand changeability to any market environment. The phenomenon of using the integration of lean and agile in new product process development helps to improve productivity, flexibility, and competitiveness that fit customer-changing requirements by eliminating all forms of waste that lead to redundancy, obsolescence, and firm extinction proactively. Currently, no study has shown a systematic method to integrate the synergy of lean and Agile to reduce waste proactively which is currently affecting manufacturing /production/service firms. This problem continues to bring financial burden that results in extinction on most firms with limited resources to withstand the shock of possible financial losses. The modern global market environment has shown clearly that every environment is likely to experience either a steady or an unsteady

market presence which has become very challenging to firms as globalization increases because most new entrants bring different market technological strategies to earn a market share. The proposed study focused its background on a superior understanding of issues that underpin the underperformance of products to fit customer-changing requirements in today's market environment, and design methodology to reduce these problems so that it will automatically add new value to the new product development processes. Moreover, the study focuses on the impact of using a single tool of lean or agile, and the integration of both tools of lean and agile as a single tool to offer a distinct product synergy of robustness and smartness to increase product adaptability efficiency to any market environment.

1.2 Statement of the Problem

The inevitable impact of globalization and technological evolution has led to the underperformance of new products to fit customer-changing requirements in this present 21st century. The situation of today has created rapidly changing customer requirements that continue to lead to all forms of waste such as redundancy, obsolescence, and abandonment. Moreover, the situation has continued to be the leading cause of loss of sustainable strategies, profit, and struggle for the extinction of most manufacturing/production firms. The global market of today requires excellent responsiveness to fit the dynamics of customer-changing requirements to the rate of technology evolution and globalization momentum to reduce both value and non-value add waste effect. Therefore, the problem of underperformance of products in the 21th century is caused by several market disturbances such as high-volume customization, incremental demand, competitive advantage, etc., which result in turbulence as both technology and globalization evolve to create new emerging markets.

1.3 Aims and Objectives of the Research Study

The study aims to design a methodology to integrate lean and agile processes systematically and successfully into a new product development process to adapt both stable and unstable market environments resulting from the forces of globalization and technological evolution because none is currently in existence. The study also aims to discuss the integration of lean and agile in the context of push, which is a lean process, and pull strategy which is an agile process in a new product process development. The context of new product development requires inbound and outbound logistics during the procurement and flow process in different phases of new product development. Therefore, the study also aims to discuss the total zero cycle time and zero lead time that is inevitably in

existence/practice during new product development which is the relevant source of waste that causes underperformance experience by most products today. Moreover, the study aims to provide a systematic approach for adopters to understand how to apply the tool of lean and agile as a single to correct the problem that causes underperformance.

1.4 Significance of the Study

The research study aims to eradicate inevitable obsolescence, redundancy, and abandonment experienced by manufacturing/production firms as technology evolves and globalization continues to spread to create n Additionally, the research intends to help manufacturing/production/service firms utilize the synergies of lean and Agile to offer a new product process development a vantage of embedded robustness and smartification that will overcome the effect of market disturbance and complexities so that it will continuously fit customer-changing requirements in a 21st -century era. Additionally, the research study will provide manufacturing/production/service firms with a single miniaturized systematic tool to manage both predictive and unpredictable global market environments. Also, the research will offer the manufacturing/production/service firms in a global market environment an opportunity to use the synergy of lean and agile to create values that can manage both stable and turbulent market environments regardless of volume of customization to fit customer changing requirements. Moreover, the integration of lean and agile provides synergy to manage product life cycles responsively and consistently will help to reduce obsolescence, redundancy, and abandonment during new product process development phases. Additionally, the integration of lean and agile helps to refine value chain dynamics and product life cycles to continuously fit customer-changing requirements in a global market environment.

1.5 Concept and/or Theoretical Framework

The theoretical framework of the proposed research study based its structure on the integration of the synergies that exist between lean and agile manufacturing which can be refined to the theory of robustness and smartification. Moreover, this refinement has a vantage process capability increment that will continuously improve productivity, flexibility, and competitiveness. The study framework was based on process integration model framework that supports systematic thinking in a practical approach on how to combine large modeling and

manipulation of different models/theoretical framework once a suitable representation is identified (Bitkowaski et al., 2023; Dolk & Kottermann, 1993; Friedler, 2009; Pop et al., 2023). Process integration model is a combination of different theoretical frameworks in one process (Bitkowaski et al., 2023; Dolk & Kottermann, 1993; El-Halwagi, 2006; Friedler, 2009; Pop et al., 2023; Toro-Jarrin et al., 2016). . Process integration models can combine many theoretical frameworks such as system theory, interoperability theory, collaboration and coordination theory, business management theory, data integration theory, adaptation theory, mathematical modelling and optimization theory etc. in one process (Bitkowaski et al., 2023; Dolk & Kottermann, 1993; El-Halwagi, 2006; Friedler, 2009; Pop et al., 2023; Toro-Jarrin et al., 2016). Process integration model provides a practical approach of combined thinking approach, and this is why it is a concept drawn from various disciplines such as engineering, operations, business management, operations management, operation research, and system theory etc. (Bitkowaski et al., 2023; Dolk & Kottermann, 1993; El-Halwagi, 2006; Friedler, 2009; Pop et al., 2023; Toro-Jarrin et al., 2016). The theoretical framework of this study was based on process integration of lean manufacturing modelling and blue ocean manufacturing modelling to develop six action frame work. These two modelling were selected because there is a synergetic interaction that exists between lean manufacturing processes that eliminate non-value add that supports product robustness, and blue ocean manufacturing agile process that support product smartification that reduces lead time waste (Sadiq et al., 2021; Schuh et al., 2019; Sushil and Dhir, 2024). The study selected the concept of lean manufacturing concept and blue ocean manufacturing (B.O.M) integration concept to develop a six-action framework that will offer sustainability to new product development of temperature measuring instruments as technology evolves. The integration of lean manufacturing and blue ocean manufacturing is outstanding to handle this level of system complexity that involve several modelling. Lean manufacturing uses systematic approach to continuously identify, adapt, eliminate non-value add activities, improve efficiency, and cost reduction. Blue ocean manufacturing is a dynamic system that focuses on new value creation that utilizes four actions framework that consist of eliminate, reduce, raise and create. Blue ocean manufacturing process creates new uncontested market space

through innovation opportunities rather than competing in existing or saturated markets. Blue ocean manufacturing redefines value creation boundaries as technology and product life cycle evolves. The use process integration thinking is most advanced engineering technology in the world as of today because of its system engineering complexity and system thinking miniaturization integration (Bitkowaski et al., 2023; Pop et al., 2023). Lean and agile systematic integration methodology is a complex study that only process integration model can allow this level of complexity, flexibility, profitability, sustainability, and sharing of models from different disciplines (Bitkowska et al., 2023; Dolk & Kottermann, 1993; El-Halwagi, 2006; Friedler, 2009; Pop et al., 2023; Toro-Jarrin et al., 2016).

The research framework of process integration will utilize a six-action framework design that will help to technically craft a miniaturized single tool from engineering and business perspectives. The miniaturized tool will integrate synergetic quality of lean and agile manufacturing to support new product process development that fits customer-changing requirements regardless of any type of disturbances or complexities that exist in any market environment. The research study will conduct its findings using a paradigm that will consist of lean and agile processes to reveal the practical application of both tools in new product development. Moreover, the study will use a paradigm of a six-action framework that will be designed to continuously fit customer-changing requirements to any volume of predictability and unpredictability in a global market environment. , The research study will entirely use six action framework processes that will consist of value identification and mapping, value feedback control, Value flow pattern design, value deployment, value review assessment, and new product launch to show a successful application of lean and agile process in a new product development. The theoretical framework of the study will utilize a flow chart to represent a step-by-step approach of the six-action framework methodology to solve the problem of product underperformance problem which will help to support both the manufacturing company and service company to remove the inevitable obsolescence, redundancy, and

abandonment that exist in most of their process which is the leading cause of loss of profit and extinction of firms as technology evolves and globalization spreads. Also, a flow chart will help to provide an illustrative process that reveals visually how the rapidly changing market environment caused by technological evolvment and globalization traits, can be continually revolutionized in a way to fit customer changing requirements of today`s global market. The use of a flow chart was designed to help provide an extensive self-learning experience and practical experiment that serves as a manual guide that will help firms visualize the successful integration of lean and agile processes in modern times of today's market environment. The flow chart helps with the difficulty experienced by most firms to respond responsively with a better strategy to support a transient competitive advantage that creates an uncontested market space. The flow chart provides excellent step-by-step visibility that helps the organizational manager to track the root cause of failure at any time through a critical understanding of all environmental factors and reactants that will always play a relevant role during the operation of any phase.

The Flow Chart of the Theoretical Framework of Lean and Agile process Integration

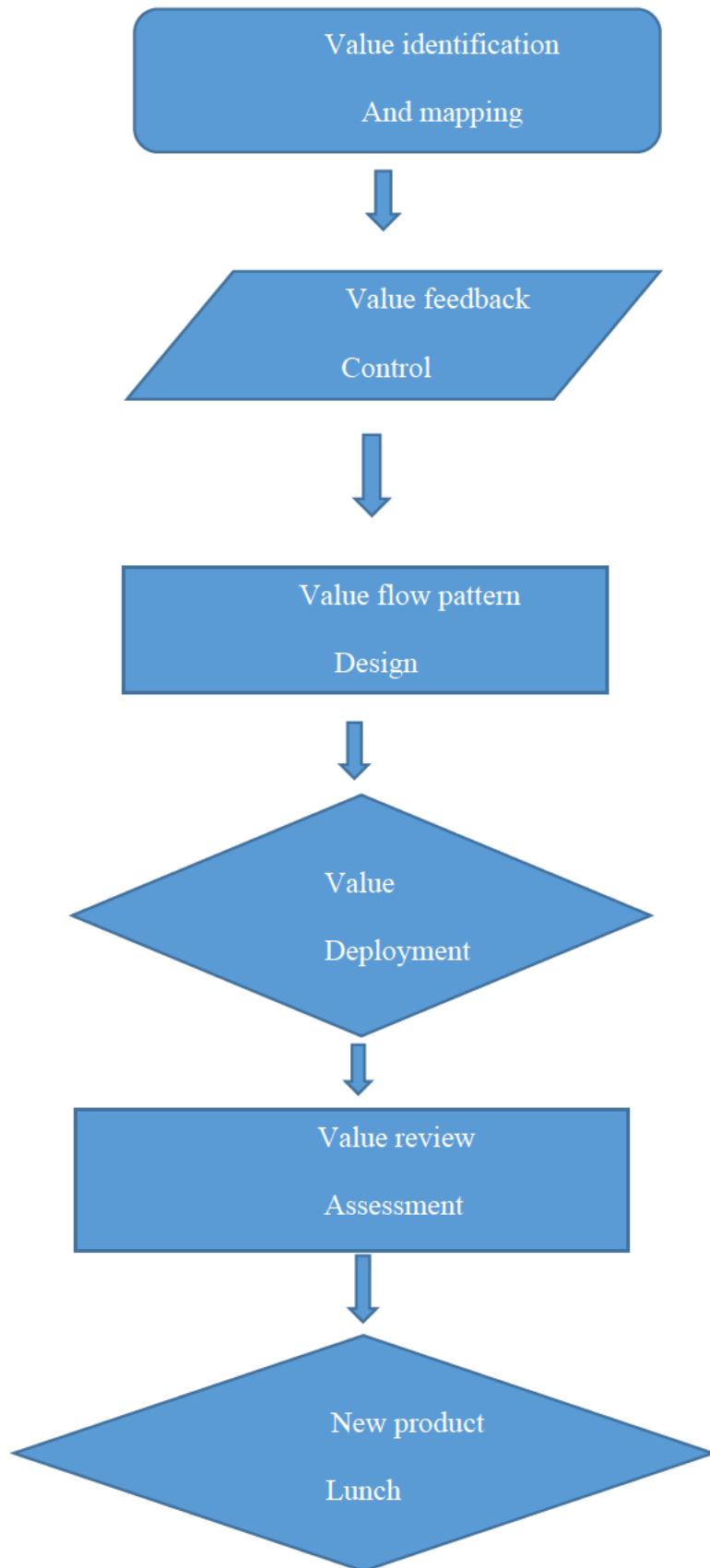


Fig 1.0 Flow chart of lean and Agile manufacturing/production of new product process development

The flow chart diagram above in Fig 1.0 reveals several relevant aspects but the greatest of it all is the ability of the process to replicate itself uniquely and more rapidly than ever which lowers new product process development life cycle time to fit customer changing requirements that supports management of high volume customization and sudden market disruptiveness by competitors. Moreover, these abilities to replicate uniquely and rapidly utilize the principle of robustness and smartification to eradicate the presence of waste that causes obsolescence, redundancy, and abandonment that have the likelihood to lead to loss of profit that threatens a manufacturing/production firm to extinction. The flow chart in Fig 1.0 reveals how the product of the synergetic quality of robustness and smartness can provide extensive ability for a manufacturing/production/service firm to profitably manage the product life cycle of its value chain creation to fit customer-changing requirements. Moreover, the flow chart also reveals the ability of the six-action theoretical framework structure to capture all processes of new product development which offers a vantage of unique productivity improvement, flexibility, and competitiveness that fit customer changing requirements in the present global market of the 21st century. The flow chart structure reveals from the product life cycle management perspective that the synergy of robustness and smartness can rapidly improve a new product process development by adding a new value to the product life cycle maturity stage before the product life cycle reaches decline and this creates a transient strategy of a new product launch into the market environment. Transient strategy offers uncontested market space that lead market competitors to act responsively. Moreover, the synergetic quality of robustness and smartification helps a manufacturing/production firm to responsively eliminate the problem of obsolescence, redundancy, and abandonment that a product will suffer during new product development cycle declination management due to various disturbances and complexity that will be inevitably present .

1.6 Research Methods

The research study is a quantitative model that utilizes the design of experiment (DOE) statistical approach which is popularly known as the factorial experiment but with emphasis on the Taguchi DOE simulation method. The research plans to use both independent variables in the form of factors and dependent variables as outcome of the simulation. The study will use eleven factors and two-level interaction to study the application of lean and agile processes to eradicate/minimize the current underperformance that is currently experienced in new product development. The factorial experiment will traditionally require 2048 trials

using eleven factors at two-level interaction, but the proposed Taguchi DOE method will reduce the experiment to Twelve (12) simulated experiments. The Taguchi will reveal the interaction of eleven independent factors/variables that produce dependent variables. The research method will also use ANOVA statistics to determine most of the hypotheses raised by the studies. The DOE method was selected because the study involves a type of factorial simulation that requires the determination of the effect of several independent factors or variables, both independently and in interaction with each other at different levels simultaneously at longer periods than a simple trial. Therefore, every study carried out for longer periods for more than 100 trials is expected to provide a more reliable and valid result by providing structural equation modeling (SEM) and Hierarchical linear modeling (HLM) that helps to detect changes in outcome on the same trial over time. Moreover, the SEM analysis is made up of the confirmatory factory analysis (CFA) and explanatory factory analysis (EFA) which helps to find potential measurement errors that the study can not control because of various observed variables during trajectory identification in the context of latent curve model (Bollen & Curran, 2006). The HLM will be used to analyze the longitudinal repeated-measure (HLM) data to explore the effectiveness of different performances to understand all related benefits of interaction. Therefore, the use of the DOE method provides better reliable and valid result for this type of studies.

1.7 Research Question

The research question (RQ1) of this study is: “Does lack of engineering integration of lean and agile processes cause underperformance of a product to satisfy customer changing requirements in a global market environment of the 21st century”?. The research question was crafted to cover the problem statement of the research study so that appropriate methodology on how to solve the present product underperformance problem can be achieved using the synergetic interaction of lean and agile tools. This problem of underperformance is currently experienced by most manufacturing/production/service firms in the global market environment of the 21st century. Moreover, the research question concisely focuses on determining how the integration of lean and agile manufacturing processes will offer the synergetic quality of robustness and smartness to fit customer-changing requirements in a market as technology and globalization evolve. Furlan et al., 2023 highlighted that there is a need to develop a way to integrate lean and agile processes into product development to help support better quality and efficient products.

1.7.1 Research Hypothesis

The study's hypothesis investigate three important closely related phenomena. Moreover, the research hypothesis will utilize null (H0) and alternate hypotheses (Ha) to test the first, second, and third hypotheses mentioned below to justify the statistical relevancy of the study.

First hypothesis test, (H01): Lack of existing systematic methodology to integrate lean and agile successfully during product development is the leading cause of waste that causes redundancy, obsolescence, and abandonment. (Ha1): The use of a systematic methodology to integrate lean and agile into new product development will help the firm to adapt to both stable and unstable market environments that will reduce waste of all forms.

Second hypothesis Test, (H02): Lack of existing systematic methodology to integrate lean and agile successfully is associated with inefficiency and ineffectiveness in the management of push which is lean thinking, and pull which is agile thinking strategy during new product development. (Ha2): Use of a systematic methodology to integrate lean and agile into new product development positively removes all forms of waste during the management of a push and pull strategy that supports high efficiency and effectiveness that fits customer satisfaction and expectation.

Third hypothesis Test, (H03): None existence of a systematic methodology to integrate lean and agile successfully creates increased complexities and inefficiencies in managing total zero cycle time and zero lead time. (Ha3): use of an appropriate systematic methodology to integrate lean and agile into new product development removes complexities, inefficiencies, and simplifies how to manage firm resources during value creation that will positively manage zero total cycle time and zero lead time that fit customer changing requirements.

1.8 Limitation of the Study

The limitation of the study is that it will only focus on in-depth discussion and design methods for the integration of lean and agile manufacturing processes in a new product process development. The study is only applicable to manufacturing/production/service industrial process that creates value and offers value that fits customer-changing requirements in a global market environment. Moreover, the study is only limited to synergetic quality of robustness and smartness derived from lean and agile which will be utilized to disclose how to improve productivity, flexibility, and competitiveness of a new product process development to overcome the underperformance of product to fit customer changing requirements in the global market environment of the 20th century.

The study will not use traditional industrial machine processes of any form but only use simulation of the manufacturing/production process environment using the design of the experiment method with much emphasis on the Taguchi approach to complete its investigation. The study is limited to synergetic quality of robustness and smartification even though several other synergies may exist during lean and agile integration. The study will use a human temperature measuring instrument used in a hospital as a case study that focuses on quality improvement during new product development.

1.9 Delimitation of the Study

The study is not limited to using only the simulation analysis approach of the design of the experiment using the Taguchi approach alone, but ANOVA will also be included to investigate and compare the study results on different statistical approaches of DOE and ANOVA to determine the relevancy of the application of lean and agile integration during new product development. The idea of simulation by the design of the experiment will include all cost assessment, profitability, validity, reliable results, etc. that reveal the relevancy of integrating synergetic quality of lean and agile. The study is not limited to only the discussion of the application to hospital temperature measuring equipment but also to other vital engineering applications that use manufacturing/production engineering processes that create and manage values that fit customer-changing requirements in a global market environment.

1.10 Organization of the Study Relevance

The study was organized, in a way to discuss some relevant aspects that will support a comprehensive understanding of all stakeholders (Academia, adopters, and practitioners) which will support future innovation on the application of lean and agile processes in all aspects of human endeavor that creates value for customers. This section will discuss the following subsections such as: new product development, lean and agile manufacturing integration, product robustness in product development, smartification in product development, and innovation research gap and its application.

1.10.1 New Product Development

The concept of new product development is very complex but the context in this discussion will consider product development as a disciplined problem-solving approach toward fulfilling customer needs. Moreover, product development as a disciplined problem-solving originates from Japanese product-development practice in the mid-1980s. Moreover,

product development in the context of a discipline of problem-solving is assumed to be a balancing act between relatively autonomous problem-solving by project teams, organization leaders, top managers, and overarching product vision. The study found that product development consists of a set of activities that allow for product creation from concept ideation to production and it is the time when most decisions regarding products are made. The study found that new product development processes significantly influence the performance of product design and development systems. Also, the research held that the new product development process (NPDP) consists of a sequence of stages and activities that a firm employs to conceive, design, manufacture, and commercialize a product. The success of new products is determined by time, cost, and quality to fit competitive changing customer requirements. Additionally, The study found that the architecture of the new product development process is significantly influenced by many factors such as technology, management strategies, business goals, policies, culture, beliefs, etc. and it impacts the success of product development. The study found that new product development process models are an explicit flowchart that reveals how a product will be produced. Perhaps, the flowchart can include a series of stages that can be assigned to functional team members to accomplish specific deliverables.

1.10.2 Lean and Agile Manufacturing Integration

The research study found that product development activities are generally unstructured and complex when compared to other business processes such as operation and manufacturing that impact productivity efficiency. The study found that only lean tools\ techniques can not be used in product development without major modification because of the presence of complexities. Lean reduces waste and increases efficiency in a manufacturing system, but it cannot deliver products faster than competitors to satisfy consumers' expectations without modification of its system because of its inability to overcome all forms of market disturbance. Moreover, the study found that a hybrid strategy that combines lean and agile is relevant to managing predictable demand and unpredictable demand. Lean is good for stable market demand while the agile technique is good for volatile, and highly customized markets. Additionally, Product development processes are affected by the influence of the leader, time-to-market pressure of the product, range of products, confidence of the leader, and managerial control process because it creates different forms of disturbances that can cause market turbulences. Also, the study found that the idea of integration of lean and agile can be applied in other areas that related to product development of manufactured goods such as service development industries. Consistently, the integration of lean and agile will offer a competition strategy that will help the firm to develop a transient competitive advantage that

improves product life cycle with unique speed and flexibility to product market launch that will prevent a firm's product from experiencing obsolescence, redundancy, and abandonment due to market disturbances and complexities.

1.10.3 Product Robustness in Product Development

Product development activities experience all forms of disturbances that pose risk to the manufacturing/production system which impacts its performance. Production system disturbances and complexities vary based on entities against the production system and such entities might include environment, value creation technology, leadership, management control, production techniques, market pressure, resources, etc. Moreover, the study found that a robust production system is a type that can be able to deal with disturbances while maintaining high performance during its operation. A system is said to be robust when it exhibits features of resilience, agility, flexibility, or changeability while maintaining high performance during its operation. The performance of a production system is said to be robust when it can maintain stability, for instance, if a turbulent market in a high-volume customization environment reacts against disturbances and adapts or withstands its effect while fitting customer changing requirements. The robustness of a system can be expanded to include multiple key performance indicators because a system might include several target functions to maintain stability. Moreover, the research found that the robustness of a system can be measured in terms of changes and uncertainties, therefore flexibility is an enabler of robustness. The modern production system requires flexibility and changeability while maintaining robustness to entirely reduce the negative effect on performance during adaptation to a different market environment that uses either lean or agile technique . The study found that flexibility is a type of changeability that focuses on the production segment and only allows adaptation and change within a defined boundary. Also, the research found that an agile production system converts quickly and smoothly without a predefined or planned adaptation method which is the main difference between agility and flexibility. Therefore, agility allows adaptation to contain bigger disturbances than flexibility because it could adapt to quick changes in the corporation. Perhaps, the quick adaptation to market demand changes allows it to deliver products to customers on time than competitors. The research found that resilience is the ability of a production system to tolerate disturbance while it occurs either by adapting to a new situation or by building resistance towards disturbances without adaptation. The manufacturing system of today continues to experience high disturbances as globalization and technology evolve which continue to create new emerging markets that cause underperformance of a product in its environment. Therefore, today's manufacturing system is struggling with various disturbance effects to fit customer-changing requirements which continue to cause a firm to experience product

obsolescence, redundancy, and extinction within its market environment. The research found that risk is the effect of uncertainties on objectives, and this can be attributed to the leading effect of underperformance. Also, A system is said to be robust when it can manage uncertainties that result from various disturbances in such a manner that it does not offer an undesirable performance to a production system. The concept of robustness can be among the perfect tools to manage market disturbances such as high-volume customization and demand while maintaining the high performance of a production system.

1.10.4 Smartification in Product Development

The research found that the phenomenon of smartness is used to describe products that are extended with digital functions and customer-oriented services. Moreover, Smart features improve a company's product development using the extended digital function that combines physical appearance to achieve maximum customer satisfaction through different automation systems. A firm will always face new disturbances during changing customer requirements, new customer demand and new technology such that a need for smart product features is inevitably necessary to manage uncertainties that will originate from different forms of disturbances. Technically, for instance, there are huge disturbances that exist between human-machine -interface, data processing, and IT infrastructures which require proactive action to handle these uncertainties that will help to fit customer-changing requirements. Moreover, the research found that smartification is a digital refinement of an existing product by embedding digital technology and smart services to offer the product a new performance.

Therefore, when a new smart technology is embedded in a product then it implies that a newly completely improved performance has been offered to the product automatically which helps to overcome the effect of disturbances proactively. A firm can automatically, and proactively apply continuous improvement by embedding digital technology into its existing product to offer a completely new performance to the product so it can withstand market uncertainties or turbulence that a traditional lean reactive process cannot handle. The market of today in most situations requires the product to be embedded with more than one digital technology to boast higher intelligence that will offer a sustainable transient competitive advantage against various environmental disturbances and complexities that might lead to the underperformance of a new product development.

1.10.5 Innovation Research Gaps and its Application

The proposed research targets to provide a solution path that will be universally applicable to different forms of manufacturing/ production/service activities to tackle the problem of

underperformance of the new product development process. The gap of this innovative research is that this work will provide a systematic structured application of lean and agile using the synergies of both tools in the context of robustness and smartness quality to solve the problem of product underperformance that leads to obsolescence, redundancy, abandonment, and extinction of firms in its market environment. The closest attempt to implement lean and agility was proposed by Leite et al., 2016 in a research publication captioned "A road map for implementing lean and agile techniques in SMSEs product development teams". Leite et al., 2016 study suffers heavy issue when use by most practitioners and industrialists because the work only makes relevant suggestive benefits and its relevant application but have not properly reconcile the best structured systematic method(step-by-step approach) on how to manage the zero total cycle time of lean activities and the zero lead times activities in new product development. The lean-agile is the critical integration of lean thinking and agile thinking process in new product development. The Leite et al., 2016 studies and all other related studies failed to show how to achieve zero waste total cycle time and zero waste lead time in a structured design. This failure has led to significant drawbacks for the adoption of lean and agile technical industrial applications. The failure of the entire adoption restrict manufacturers and the service industry towards lean-agile implementation and it is justifiable because a structured technical methodology provides further engineering investigation towards the possible success of a phenomenon or its application before adoption. The work of many studies has not clearly shown a structured methodology to reconcile waste that exists between market knowledge and virtual corporations during the product development process to explore the relevant profitability of its research study in today`s global market environment. The failure of the previous study was because it failed to reveal how to practically achieve zero total cycle time on the lean thinking process of product development such as zero waste time, zero waste material flow, zero waste labor, zero waste capacity, etc. and zero lead times at the agile thinking process such as efficient and effective virtual corporation of value creation, zero total information flow and product delivery flow etc. Therefore, these omissions are the critical interface that explains how to use the lean and agile application to achieve zero total cycle time and zero lead time, and this limits the systematic synergetic quality of robustness and smartification that is required to overcome the effect of different forms of disturbances and complexities that inevitably exist during new product development process that fit customer changing requirement. Moreover, the research study to this date was very impressive because it creates a road map to the lean and agile thinking process, but the study cannot be an appropriate integrative tool for adopters to apply lean and agile process systematically in a context of a new product development process due to unstructured insufficient information on coordinating zero total cycle time and zero lead time management process to fit customer changing requirements. Also, the same problem applies to earlier work of lean and agile.

The study found the need to adopt lean agile but did not provide a structured systematic methodology on how to adopt or manage the zero total cycle time and zero lead times which will help to understand how lean-agile process integration can be applied in new product development. Also, the same issue of not having a proper explanation for zero total cycle time and zero lead time draws skepticism to the research study of McArthur and Bortoluzzi, 2018 on lean–agile application adoption which is highly unstructured. The research study found that only value-adding content (lean) that develops flexibility and iteratively in collaboration with end-users (Agile) but most studies never discuss how to manage zero total cycle time on the lean activities during value-add which flexibility alone will cause waste on high volume customization, and how to manage zero lead time in the information flow during collaboration with end users which help adopter to understand the method to be able to replicate it to fit their production process. Moreover, another major issue to the adoption of lean-agile study from all the previous studies is that there is no structured systematic methodology for managing the lean-agile thinking process to achieve zero total cycle time and zero lead time which opens a path for constructive engineering investigation of proper application of synergetic quality of lean and agile (robustness and smartification). The research innovation gap in this study is to provide a comprehensive structured systematic methodology that integrates the lean thinking process that focuses on zero total cycle time and the agile thinking process that focuses on zero lead times which will produce an outstanding quality performance of new product development than a single approach of lean or agile in new product development. Also, the integration of lean, and agile processes will help to tackle the problem of fatigue, adaptive responsiveness, and all forms of disturbances and complexities to eliminate obsolescence, redundancy, and abandonment as the volume of customization continues to increase to high uncertainties since globalization increment and technology evolution is inevitable. The research innovation gap is to provide a sustainable comprehensive structured systematic methodology that integrates the lean thinking process that focuses on zero total cycle time and the agile thinking process that focuses on zero lead times which will produce an outstanding quality performance of new product development than a single approach of lean or agile in new product development. This issue has brought a problematic tension in production management because of product underperformance for over two decades without a structured solution to this date (Furlan et al., 2023; Roberston & Jones, 1999). This study is designed to put an end to this problematic tension by providing a systematic methodology that will allow successful integration of lean and agile as a single tool that offers synergetic benefit. Also, the integration of lean, and agile processes will help to tackle the problem of fatigue, adaptive responsiveness, and all forms of disturbances and complexities to eliminate obsolescence, redundancy, and abandonment as the volume of

customization continues to increase to high uncertainties since globalization increment and technology evolution is inevitable.

1.11 Summary of the Study Chapter One

Chapter One of the study focused on discussing the background of the study, statement of problem, significance of the study, theoretical framework, research questions, hypothesis, limitations of the studies, study organization, summary of the chapters of the study, and conclusion. Chapter one disclosed the basis and the relevancy of this study and its application to human endeavors to alleviate manufacturing companies from their current productivity predicament that is currently suffering a huge amount of inefficiency and ineffectiveness in this date on the present global market of today which is the leading cause of most product underperformance.

1.12 Validity and Reliability

The study conducted a validity test on the Taguchi experiment during the experimental phase by repeating the simulations result at the predicted optimal settings to examine consistency. Also, the study used ANOVA to verify the significance of the factors. The study maintains consistency in the use of Taguchi DOE software during the entire study investigation. The study maintain consistency during data collection that was used in the statistical process and Taguchi DOE application. The study performed reliability testing using Taguchi orthogonal array. The study set up a define variable and use Taguchi orthogonal arrays to define the experiment runs. The reliability produces the same result after several runs and the study check for any variation with the optimal setting and none was found. The study determines that the Taguchi software was reliable.

1.13 Ethical Consideration of the study

The study used Taguchi software experimentation that does not involve any form of human physical invasive, or potential harmful procedure. The procedure only involves interaction of the investigator with a Taguchi software and a laptop connected to a high-speed internet. The investigator maintains all laboratory safety during the experiment investigation. The Taguchi software use by the investigator followed proper acceptable compliance for intellectual property protection right. The investigator observed excellent data management during the entire experiment. The ethical application was made by the investigator to use the software, and it was permitted by the Engineering graduate school after ethical compliance check.

1.12 Conclusion

The research motivation aims to reduce the underperformance of new products to fit customer-changing requirements in the global market environment. The underperformance

of new products in the global market creates immense waste, which is the leading cause of manufacturing/product firm`s poor productivity output, poor flexibility, and poor competitiveness resulting from underperformance, which is the motivational force that influenced the investigator's interest to lead this study to solve the human critical need of today`s global market. The impact of underperformance is among the leading causes of extinction of most firms due to loss of profit created by waste resulting from obsolescence, redundancy, and abandonment which gives the investigator a great concern on how best to solve this problem. The research objective of the investigator in this context is to strongly demonstrate the engineering application of lean and agile synergies in new product process development. Moreover, the research objective will strive to demonstrate how the integration of lean and agile manufacturing/production processes improves efficiency and effectiveness of productivity, flexibility, and competitiveness in the global market environment of the 21st century. The study motivation aims at strongly utilizing the synergy of lean and agile to help manufacturing/production firms reduce inevitable obsolescence, redundancy, and abandonment resulting from the impact of globalization and technological evolvment that leads to waste of different forms. Additionally, this research study also aims to manage the value chain dynamics of manufacturing/production firms that will help to improve productivity, flexibility, and competitiveness in a global market environment. The research study motivation was strongly stimulated since it applies to all human endeavors that create and offer value to customer-changing needs in a global market environment regardless of market environment. The essence of this study is to add a method of synergetic integration of lean and agile to existing knowledge which was excellently motivated by the relevancy of its application to different forms of value creation in several human endeavors, and it offers an exceptional vantage to productivity improvement, flexibility, and competitiveness that help to reduce underperformance of new product development.

LITERATURE REVIEW OF THE STUDY

The literature studies concluded that the use of a lean process helps reduce waste, and it makes the product more cost-effective and competitive in that it satisfies customer needs. The study acknowledged that the lean process tends to attract new/ and existing customers because of a reduction in the cost of production and resource utilization maximization that support pricing strategy. The global environment of today continues to increase the volume of customization, and it involves rapid improvement that requires a lot of capabilities such as speed, cost, productivity, lead time, proactive quality management, etc., to respond to customer market needs and competitor's disruptiveness. The agile tool process helps firms to respond to competitive strategies where change is continuous and unpredictable with a high volume of customization that fits changing customer satisfaction. The application of lean and agile continues to be crucial in new product development regardless of the production strategy used because inevitable waste from cycle time and lead time exists in make-to-order and make-to-stock. The inevitable presence of waste is the leading cause of the underperformance of a product, and it makes it difficult for firms to create values that fit customer-changing requirements. The problem of underperformance has caused most firms to lose profit and suffer extinction from their market environment. The study focuses on providing relevant solutions on how to tackle this problem of underperformance by disclosing step - by a step-by-step approach on how to integrate lean and agile into a production system to eradicate the inevitable waste from cycle time that originates from the lean process and lead time agile process.

2.1 Lean Manufacturing

Lean manufacturing/production was categorized as the third phase of industrial production in the modern world. The initial phase of industrial production started with craft production which involves craftsmen completing an individual project to customer specification. The second phase was the mass production phase which was invented by Henry Ford to support increased global need and demand although the product variety was at the minimum level at the early stage. The third phase was lean production invented by the Japanese which took advantage of mass production's inability to eliminate waste that will help to reduce costs. Moreover, Lean production was designed to minimize cost by removing non-value-added activities by using fewer inputs to achieve a higher amount of input. The Lean manufacturing/production was invented because mass production failed to satisfy the changing customer requirements to lower costs, reduce waste, and improve quality. The lean/manufacturing was design to better enhance the product to support better customer expectations as technology evolves. Moreover, Lean manufacturing tends to allow effective

utilization of all resources compared to mass production which does not use the full creative talents of its employees and other resources that impact productivity. The relevant need for adopting lean is to increase productivity, enhance quality, shorten total cycle time, and drastically reduce cost which is good for a stable market and not for a turbulent market with greater disturbances. The research found that lean application has been adopted in several instances in the different manufacturing processes to support waste reduction during new product development, regulate variability during quality control, manage process flow to eradicate delay time effect, and support continuous improvement.

The research also found that lean manufacturing has been used during product development to reduce waste and support value increments that fit customer requirements. Also, most previous studies held that lean manufacturing has been used by Toyota's production system to continuously improve its productivity towards waste reduction, quality control, process flow, continuous improvement, and value add, etc. which have offered a competitive advantage against competitors. Additionally, the research found that lean manufacturing is very relevant in manufacturing because it creates a road path to innovation that fulfills the customer-changing requirement in its market environment. The research found that the lean manufacturing concept helps to support the human ability to regulate manufacturing defects and helps to reduce the cost of inspection and correction of defects in a finished product. The research study found that lean manufacturing helps to provide root cause analysis that provides the problem-solving methodology for a corrective action that enhances the continuous flow of production/manufacturing without bottlenecks. Also, the study found that lean can be used to measure the rate of accomplishment by measuring output against demand, and this helps to fit customer demand requirements.

2.2 Agile Manufacturing

The concept of agility manufacturing/productivity started about 1991 in the United States and the UK because of market disturbances that result in turbulent that exists in a business environment that dominates the manufacturing environment as a firm strives to compete responsively to avoid extinction that results in product obsolescence and redundancy. Additionally, the research study found that agile manufacturing/production offers responsive adaptation that strongly overcomes market disturbances and complexities, shortens lead times, and increases business performance output in a turbulent market environment. Moreover, Agile productivity provides the mechanism to embrace change that can survive turbulent competition because it offers a firm extensive capability to identify opportunities proactively ahead of competitors to fit customer changing requirements. The agility implies the ability to think and reconstruct operations, processes, and business relationships, quickly and efficiently. The research found that agile manufacturing offers

ultimate performance that lean manufacturing cannot offer because the lean approach supports only cycle reduction time with the inability to contain high-volume product customization that fits customer - changing requirements in a turbulent market environment. The phenomenon of agile manufacturing reveals the need to emphasize the need to enhance speed and flexibility in manufacturing/ production/service that will adapt sustainably in a turbulent market environment. The phenomenon of Agile manufacturing has expanded customer satisfaction to a greater complexity beyond cost and quality to fit customer-changing requirements in a turbulent market environment to overcome the effect of underperformance resulting from disturbances and complexity. The context of Agile manufacturing focuses on how to effectively respond to continuous change or adapt in a manner to overcome all forms of disturbances using its enablers to support customer-changing requirements. Moreover, the study found that agile manufacturing/production performance depends on using the most compatible methodology that enhances enablers in a particular market environment. The research found that agile manufacturing provides increased visibility among teams at every stage of product development which helps to prepare upcoming tasks for delivery. The idea of agile can be technically interpreted as the phenomenon of having market knowledge and a virtual corporation with customers to exploit opportunities in a volatile market environment.

2.3 The Need for Lean and Agile Application Process

The application of lean and agile has consistently gained momentum since 1999 when the two prominent scholars Robertson and Jones proposed of using both lean and agile applications in the service industry of British Telecommunication plc (BTC) to improve the underperformance of productivity in communication services. Moreover, the study found that the Toyota production system agreed that lean and agile can be merged during the analysis of the push (lean) and pull (agile) operations of the Toyota production system. Moreover, the study found that a theoretical proposal that did not indicate or provide a practical systematic design on how this integration of lean and agile need to be done which is the focus of this research study. The research study focuses on providing a refinement of a practical approach that designs how to integrate lean and agile processes in new product development to attract all firms toward its adoption. Also, the study did not find how to design integration of lean and agile should be applied to manage the push and pull strategy that creates waste to this date in the Toyota production system during new product development.

The research found that it is critically important to adopt the use of lean -agile process to overcome all forms of disturbances that cause waste that impact customer-changing requirements in a global business environment where technology evolves. The study found that most of the study provided

the theoretical relevancy of the lean-agile process as a road map but it did not provide a systematic engineering design of the integration of lean–agile application into a new product development process, and it is critical for its adoption by adopters. Also, the study found that the application of lean and agile in a facility management process helps to reduce waste and increase customer satisfaction among the end users. The study did not provide a systematic methodology on how this will be practically applied to achieve the desired quality improvement target so that adopters can successfully replicate the application. Moreover, another groundbreaking research found that lean and agile management synergy used in the construction of high-rise office buildings which came very close in its study but did not provide a systematic methodology to integrate lean and agile process application. The study acknowledged the relevancy of the application of both lean and agile processes in construction to increase efficiency and effectiveness that increase customer satisfaction by proposing that there is a need for the introduction of flexibility which will be necessary in a changing environment to support the dynamics of the lean-agile process. The study found that Nowotarski and Paslawski, 2016 work on lean and agile was unstructured and not systematic for adopters in production management to understand the step-by-step synergetic application of lean and agile to fit the process flow provided in the study that is expected to overcome the inevitable complexity (dynamic complexity, static complexity, and systematic complexity) that will pop-up during lean and agile integration.

Additionally, the study found that a critical need for corporations to integrate lean and agile processes into new product development so that synergies between lean and agile applications can be generated and utilized efficiently and effectively. The application of lean continues to trouble the production environment to this date which is the basis of this study to provide an engineering systematic design that will show step by step approach on how to apply the integration of lean and agile process during product development so that adopters can replicate it to all aspect of production management. Moreover, the research found that lean and agile integration have constraints in a complex setting resulting from change that is inevitable over time to support a shift in strategic focus in a global market environment. constructively, the research found that environmental complexity exists in three forms such as static complexity, systematic complexity, and dynamic complexity which have relevant impacts during the integration of lean and agile processes. Therefore, the integration of lean and agile leads to complexity that can be in combination of static complexity, systematic complexity, or dynamic complexity depending on global market environment force. The research study targets to use of engineering design to create a systematic methodology that will successfully manage all forms of complexity that are inevitable during the application of lean and agile processes during new product development that can successfully managed unstructured approach. Furlan et al., 2023 highlighted that there is a need

to find ways to integrate lean and agile processes to Rip the synergies between incremental and breakthrough innovations which will support the efficiency and effectiveness of the new product development process. Therefore, to this date, the investigator found that there is no current research study that has shown any systematic engineering methodology on how to apply lean and agile process application in new product development which makes this study uniquely relevant to all stakeholders of production management. Therefore, the underperformance of new products in the industry will continue to increase in today's global market as technology continues to evolve, and it will only stop until an acceptable systematic methodology to successfully integrate the application of lean and agile in new product development process exists which will help to rip incremental opportunities and breakthrough innovations. Additionally, the research found that the application of lean and agile processes in product development helps to satisfy customer-changing requirements in a global market environment by increasing overall efficiency and effectiveness in the product development management process. Moreover, lean & agile integration applications into new product development will help to improve productivity, flexibility, and competitiveness by offering a product a unique progressive life cycle that can adapt to both predictability and unpredictability market environment. Also, as globalization traits continue to spread in the environment of today, lean production which is mostly suitable for predictable demand with low variety and high volume suffers challenges to sustain rapidly the impact of changing volume customization that leads to market turbulence. The global market competition environment has led to agile productivity where a firm is required to have an excellent capability to operate profitability in a turbulent environment because customer-changing requirements are unpredictable. Therefore, the relevancy of lean, and agile integration provides firms with the vantage that either a single tool of lean or agile cannot offer in the global market of the 21st century because every different market segment has different changing market requirements as disturbances and environmental complexity respond to globalization and technology evolvement. The impact of variation in global market trends and rapid technology evolvement has inspired the movement on lean & agile applications movement which have led to new approaches and advanced processes in agile manufacturing industries to fulfill customer-changing requirements to sustain high rapid volume customization. Moreover, as customer changing requirements continue to increase, many companies continue to witness underperformance in their product set in different areas such as lead times, cost, quality, and profitability in a different global market environment which has been attributed to a lack of application of the lean and agile principle in product process development to overcome market disturbances. Additionally, the research study found that many publications on product process development using lean and agile processes has shown it has the greatest profitability of any new product which is the most important reason why

there is a relevant need to invest in lean and agile manufacturing processes that can increase efficiency to support most manufacturing firm efficiency and effectiveness. Currently, to this date, there are no existing performance metrics that define step by step to apply lean and agile manufacturing processes in new product development, and the current existing substitute which is Toyota's lean production system is not clear and does not have general acceptance among practitioners. The global market environment of today continues to reveal that a single approach of lean or Agile will not offer the required synergies that will provide improved robustness and smartness to help a firm strategically improve productivity, flexibility, and competitiveness of manufacturing in modern times because of incremental disturbances as technology and globalization evolves. Moreover, the concept of lean tools focuses mainly on just-in-time, total quality control, and waste reduction. which is more adaptable to a repetitive predictable situation that involves production standards which is a reactive process that is not capable enough to sustain a high-volume rapid change or extremely large customized continuous flow in a global market environment.

The impact of disruptive strategies by new entrants and progressive competitors as technology evolves incrementally has an influential force on every firm that exists in any global market environment, and this is the reason for firms to seek to adopt the proactive process of agile manufacturing to support its market segment from extinction which will result from obsolescence and redundancy. Moreover, the study found that no single tool of lean or agile can fulfill the requirements of customer changing needs in all market environments because of unforeseen complexity that will inevitably appear since change is permanent. Additionally, the need for firms to adopt lean and agile principles is relevant as globalization and technological evolvment is inevitable and a new product will continue to face market disturbances, complexities, and challenges to fit customer-changing requirements. Perhaps, the modern manufacturing expert\of most firms in the 20th century to this date continues to suffer poor performance in satisfying customer-changing requirements because manufacturing firm shows skeptics to the inclusion of the application of lean and agile into new product process development. Moreover, no refined methodology exists to reveal a successful structured lean-Agile application. The risk of financial loss due to the unknown outcome of the trial tends to force manufacturing managers to seek to continue with already acceptable standards. Moreover, it has been determined by several scholars and practitioners that lack of application of lean and agile impacts a firm rapid value creation increment which causes underperformance that threatens a firm to extinction. The research gap that exists between this study and previous study is that the proposed study seeks to develop a structured advanced systematic engineering methodology that will successfully integrate lean and Agile synergetic values in a single tool that offers a product necessary robustness and

smartification to adapt and overcome all forms of disturbances and environment complexity that will inevitably arise during continuous customer changing requirement as globalization and technology continue to evolve. The study seeks to bridge the gap between a reactive process and a proactive process such that it will integrate lean and agile to manage both stable and turbulent market environments. Perhaps, the greatest production/manufacturing/service manager's nightmare of today is how best to fulfill all customer needs satisfactorily and future expectations regardless of the market segment disturbance or environmental complexity constraints.

2.4 Application of Lean and Agile in Service Industry

Strategically, the service industry continues to be a critical aspect of production management that requires significant application of lean and agile to support efficient and effective value creation. Moreover, the production of a product is complete when the finished product or service is delivered to the final consumer regardless of whether it is a tangible or intangible product (Leog et al., 2019; Malifete et al., 2018; Manson-Jones & Towell 1999; Stratton & Warbuton, 2003). Therefore, the quality of a product or service plays a critical factor in managing customer satisfaction, and expectation during its life cycle (Leog et al., 2019; Malifete et al., 2018; Stratton & Warbuton, 2003; Varl et al., 2020; Victoria, 2022). Many companies have directly or indirectly introduced the application of lean and agile in service quality in an unstructured approach to achieve customer satisfaction, expectation, or advocacy, although they continue to experience product under performance to this date because there is no single existing structured systematic method that use lean and agile as a single tool to remove the inevitable waste (Leog et al., 2019; Stratton & Warbuton, 2003; Vallon et al., 2015; Varl et al., 2020). The biggest challenge of most companies depending on their market environment, is how to tailor lean and agile values that quickly fit customer-changing requirements in providing quality services that add value to the customer-changing needs (Leong et al., 219; Stratton & Warburton, 2003). Many firms with valuable resources have experience delima for adopting the use of unstructured lean and agile based on their level of experience to tailor their operation to support efficient and effective response time, error rates, customer complaints, order fulfillment, and lead time to fit customer changing requirement (Vallon et al., 2015; Stratton & Warbuton, 2003). The business environment of today tasks every organization, regardless of their market environment to improve service quality that fits customers changing needs in a way that adds value to customer offerings as technology evolves and globalization spreads competitively (Leog et al., 2019; Stratton & Warbuton, 2003; Varl et al., 2020). The idea of adopting lean and agile continues to be an attraction that many organizations wish to embrace to improve their service quality to fit the business environment of today, but there is a lot of skepticism because there is no existing systematic application of both lean and agile tool

successfully (Furlan et al., 2023; Leog et al., 2019; Stratton & Warbuton, 2003; Varl et al., 2020; Tamblin, 2024). Most organization continues to use an unstructured lean and agile operation that focuses on the concept that lean operations remove waste and improve processes, while agile provides flexibility, adaptability, and responsiveness that fit customer changing requirements that create a path to lean-agile dilemma for poorly experienced organizations (Furlan et al., 2023; Leog et al., 2019; Stratton & Warbuton, 2003; Tamblin, 2024). Victoria, 2022 held in her study that an organization could respond to customer feedback, and conduct improvements and services that fit customer expectations by embracing lean and agile tools of iterative process that offer incremental methods that fit customer changing requirements and waste reduction. Malifete et al., 2018 study held, that most organizations are adopting lean and agile operations as powerful tool to achieve service delivery exceptionality that fits customer changing needs. Many organizations in the service industry have recognized that service quality delivery has a significant impact on customer management retention strategy (Leog et al., 2019; Malifete et al., 2018; Victoria, 2022). Lyons & Ma`Aram, 2014, held that using lean to streamline the operation of an organization helps to enhance service quality that produces efficiency, and adopting agile operation prioritizes flexibility, adaptability, and responsiveness. Also, Rachid et al., 2017 study concluded that using lean and agile approaches in the service industry will significantly support organizations to quickly adapt and improve services that fit customer-changing requirements to achieve value expectations. Moreover, Victoria, 2022, Rachid et al al., 2017 and Lyons & Ma`Aram, 2014 studies revealed that the use of lean and agile operations significantly improves the effectiveness of service delivery by decreasing error, wait time, customer complaint, increasing customer satisfaction, and improve overall performance. El Khatib et al., 2021 held that the relationship that exists between lean and agile operation during service quality is symbiotic in the sense that they fill the gap of each other during operation. Aityassine et al., 2022 and Aljumah et al, 2022a study held that a combination of lean and agile helps to optimize, improve customer satisfaction, and deliver high-quality services that fit both market dynamics and customer-changing requirements. Moreover, Aityassine et al., 2022 and Ashurideh et al., 2023 studies held that the integration of lean and agile methodologies helps an organization to achieve operational excellence and responsiveness to the dynamics of a continuously evolving service environment. Also, Alshurideh et al., 2023 study concluded that the implementation of lean and agile continue to face challenges due to the complexities resulting from the difficulties in aligning processes and systems. The study of Alshurideh et al., 2023 opened a significant highlight of why most organization finds it difficult to systematically integrate lean and agile successfully to maximize the benefit of their symbiotic relationship. The difficulty in aligning processes and systems to fit customer-changing requirements creates a big hurdle for both the production and service industry because the volume of customization and speed of market dynamics

increases rapidly as technology evolves (Furlan et al., 2023; Leog et al., 2019; Malifete et al., 2018; Varl et al., 2020; Victoria, 2022). Moreover, Alshurideh et al., 2023 study concluded that difficulty in implementing lean and agile in service organizations can obstruct the full successful realization of the benefits that will provide an excellent service quality that fits customer changing requirements or needs. Also, the highlight of Alshurideh et al., 2023 study is that the concept of how to implement/apply lean and agile methodology as a single tool remains challenging due to its complexity and system alignment requirement to fit customer changing requirements. The application of lean and agile is very significant to service industry because of the inevitable effect of bullwhip resulting to increase in the volume of customization that can impact the wholesaler, distributor, and producer to create sufficient amount of inefficiencies and incremental cost (Wang and Disney, 2016; Sarker et al., 2023). Moreover, the bullwhip effect can result from complex supply chain processes, miscommunication, increase demand, high delivery time, etc which can be experienced during the service design process that creates a lot of waste (Wang and Disney, 2016; Sarker et al., 2023). The application of lean and agile will help a service industry to withstand the market dynamics of an increased volume of customized service design that continuously changes as technology evolves (Wang and Disney, 2016; Sarker et al., 2023; Victoria, 2022). The integration of lean and agile can experience environmental complexity in the customer service industry during total cycle time and lead times operation as technology evolves (Furlan et al., 2023; Manson-Jones & Towell, 1999; Victoria, 2022). For instance, a customer management department that uses a digital operation service to support its customer retention can experience bullwhip as the volume of customization increases rapidly and the digital system will struggle with customized demand increase (Furlan et al., 2023; Manson-Jones & Towell, 1999; Victoria, 2022). The bullwhip effect can cause environmental complexity that can significantly overburden make-to-order and make-to-stock as the volume of customization increases rapidly which leads to increase higher customer complaints in digital customer service (Furlan et al., 2023; Manson-Jones & Towell, 1999; Wang and Disney, 2016; Sarker et al., 2023; Victoria, 2022). The complexity in the services industry during the application of lean and agile can be attributed to environmental complexity resulting from market dynamics resulting from high volume customization and technology evolvement (Furlan et al., 2023; Manson-Jones & Towell, 1999; Victoria, 2022).

2.5 Application of Lean and Agile in Software Industry

The application of lean and agile continues to increase significantly as the number of mobile smartphone device users multiplies. Moreover, this increment is the leading cause of the development of numerous software in our global market today (Vallon et al., 2015). The continuous rapid increase in the number of active smartphone users globally has reached up to one billion in

2012, and it continues to increase to this date. The increment in active smartphone users has created an emerging market experience for the software device industry (Vallon et al., 2015). The rapid increase of the mobile phone market also impacts the dynamics of the software development market competition to fit customer changing needs as technology continues to evolve and this makes the mobile phone market very competitive with a short product life cycle (Vallon et al., 2015). Vallon et al., 2015 studies held that in real-world experience neither lean nor agile fits all the solutions in software development but most companies choose to combine both lean and agile methodologies to increase their value offering efficiently and effectively. Vallon et al., 2015 study highlighted that Scrum Lean Six Sigma (SLeSS) integration of lean (lean Six Sigma) and agile (Scrum) showed high performance during application development of the software used in mobile applications. Moreover, Vallon et al., 2015 research study questioned how to implement an agile and lean process to cope with the speed of development of the mobile application was unable to determine whether the application of lean and agile processes as a single tool can be successful in the industry but they acknowledged that practical experience will be helpful to succeed with the application. Vallon et al., 2015 acknowledged that integration of lean and agile in software development will provide significant flexibility that will increase efficiency and effectiveness that can help a company survive in its rapidly changing market environment by fitting dynamic customer changing needs. The greatest problem with almost every study on the integration of lean and agile is how the process will be designed to fit customer changing needs and the complexity of what is involved makes the most firm run risk of dilemma when using their unique unstructured approach that does not allow them to rip the entire benefit of lean and agile integration (Furlan et al., 2023; Tamblin, 2024). Vallon et al., 2015 study acknowledged that lean and agile help to overcome challenges that cover the complete product life cycle of mobile development applications and implementation. Also, Vallon et al., 2015 study held that the use of lean and agile will help to bring a mobile software product to the desired market and provide proper maintenance of the software that ensures the highest quality. Vallon et al., 2015 study also held that the integration scrum XP (Agile) and Kanban (Lean) helps to increase the flexibility of a process that provides better visualization of the work process flow that provides transparency that supports rapid efficient responsiveness. The study of Vallon et al., 2015 acknowledged that the use of lean and agile have the potential to bring a lot of benefits in the field of mobile application development but further research will be necessary to understand practical usage of the process model integration. The use of lean and agile has shown significant benefits in the software industry and other related areas, the product lifecycle is very short as technology evolves (Vallon et al., 2015). Based on the study of Vallon et al., 2015, it is clear that the biggest task faced by most firms is how to effectively apply lean and agile processes as a single tool to fit organization production strategies. Vallon et al., 2015 study acknowledged that many scholars

through their research study have shown the potential benefits of using both lean and agile processes but the greatest problem is how to successfully implement this model process. Furlan et al., 2023 study held that there is no existing systematic process model to implement the combination of lean and agile as a single tool to reap the immense benefit of their symbiotic relationship. Many companies use their combination pattern based on their level of experience which is not structured in a systematic pattern and it creates a path for dilemma in riping the symbiotic benefit of both tools as one and leadership resistance during implementation (Furlan et al., 2023; Tamblin, 2024). The application of lean and agile continues to be significantly relevant in any product or service with a short life cycle that has rapid volume customization, and its market dynamics have the potential trend to environmental market turbulence and disruptiveness (Furlan et al., 2023; Vallon et al., 2015). The market environment of mobile devices is rapidly changing every year and market competitors introduce so many different types of smartphones in the market using lean and agile methodology to fit customer changing needs (Vallon et al., 2015). The use of lean and agile is very popular because the market is covered with high uncertainty, and customer value today might be obsolete by the next day (Vallon et al., 2015). Vallon et al., 2015 revealed that the end user who is the consumer is at the last position of production completion so there is a significant need for agile to be integrated into lean because it helps to interact with the customer continuously so that the value offering will never go obsolete. Moreover, integration of both lean and agile creates better efficiency and effectiveness in understanding which non-value requires to be removed and the new value added to support customer-changing requirements (Vallon et al., 2015; Victoria, 2022). The software industry experiences a significantly short product lifecycle as technology evolves and for this reason, the use of lean and agile as a single tool helps an organization to be able to rip the benefit of outstanding responsiveness to value creation that fits customer changing needs (Furlan et al., 2023; Manson-Jones & Towell, 1999; Vallon et al., 2015; Victoria, 2022). The use of lean and agile helps to shorten both the total cycle time in software development and lead times that fit customer-changing requirements which is very relevant in short product life cycle market environment management (Furlan et al., 2023; Manson-Jones & Towell, 1999; Vallon et al., 2015; Victoria, 2022).

2.6 Application of Lean and Agile in Construction Management

The application of lean and agile concepts has been adopted in project construction management to increase the chances of successful projects (Lalmi et al., 2022). The application of lean and agile methodology offers a construction project robustness to manage complexity and uncertainties when there are rigid cost and time requirements in a complex project (Lalmi et al., 2022). The application of lean and agile to a traditional project construction management is among

the highest heights of this combination methodology concept because traditional project management methodology of waterfalls that uses a lean approach performs well with environmental certainty while agile project management methodology performs well with environmental uncertainty and higher complexities (Furlan et al., 2023; Lalmi et al., 2022). The idea of using lean and agile in construction helps to manage the problem of conflict of interest that always occurs and leads to project failure because all changing stakeholder's interests are not protected at the right time and quantity because today's construction management venture is a challenge with environmental uncertainties (Furlan et al., 2023; Lalmi et al., 2022). The use of lean and agile in project construction management helps to make a project more adaptive and flexible in responding to customer rapid change needs, who is the end user that determines the successfulness of the project delivery acceptance (Lalmi et al., 2022). The application of lean and agile in construction management helps to enhance better voice of the customer, improve team collaboration, and better responsiveness to change at any time to fit customer changing requirements (Lalmi et al., 2022). Lalmi et al., 2022 conceded that even though there is a suggestion that a combination of lean and agile is the leading project management approach, there are no existing studies that address the impact of using both lean and agile approaches in organization construction management practice. Therefore, every organization continues to use an unstructured approach that depends on their level of experience and resources which will significantly handicap their ability to have full potential to rip the benefits of a systematic lean-agile combination (Furlan et al., 2023; Tamblin, 2024). Traditionally, the application of lean and agile previously focused on software and information technology due to the speed of its market uncertainties but today construction can also benefit from higher customer involvement requirements for construction management and waste reduction needs to create a better significant path to a successful project (Lalmi et al., 2022; Vallon et al., 2015). The application of lean and agile in construction management helps to increase the customer's voice, and this helps to create better visibility on project requirements during uncertainties, and it helps to identify the actual nonvalue add and value add that fit customer changing needs (Lalmi et al., 2022). Lalmi et al., 2022 held that the combination of lean and agile methodology will offer a synergetic advantage that increases the chances of construction project management success during certainty and uncertainty. Also, Lalmi et al., 2022 study held that there is a need for a combination of lean and agile methodology during project construction management because it increases the chances of project success. Lalmi et al., 2022 study held that the application of lean and agile methodology is emerging in different fields ranging from engineering, computer, operation research management, business economics, automation control systems, environmental science, etc. Based on this emerging trait of lean and agile combination in almost human endeavor, it will be relevant that a research study develops a systematic methodology that helps to direct users on how to manage the implementation

of this complex methodology of combining lean and agile successfully. Lalmi et al., 2022, study concluded that the application of lean and agile in project construction management will provide the capability of managing different projects of varying sizes and complexities in a rapidly changing environment. Lalmi et al 2022 study acknowledged and concluded that a combination of lean and agile methodology in project construction is more efficient and effective than a single approach of either lean or agile. Moreover, Lalmi et al., 2022 further highlighted that the combination of lean and agile leverage the best synergetic feature of each other, and this is the reason why it is stronger than using a single methodology that offers only one feature. Lalmi et al., 2022 study concluded that lean construction project management (waterfall project management) performs better in dealing with static or predictable environments and agile project management performs better in managing dynamic and unpredictable environments. Lalmi et al., 2022 study concluded that a project encounters different environmental requirements during its life cycle that impact the dynamics of the project workflow towards its successful completion and for that reason, lean and agile methodology is necessary to manage both predictable and unpredictable obstacles. Lalmi et al., 2022 study concluded that a combination of lean and agile in a single methodology during management of construction projects will be better to rapidly respond to change and eliminate waste in the process. Moreover, Lalmi et al., 2022 study concluded that a combination of lean and agile is an innovative methodology that will help to cope with the complexity of construction projects and achieve maximum performance in the future. The application of lean and agile in construction and other aspect of human endeavor continues to show alarming great benefits compared to using a single approach of either lean or agile so there is an immense need to invest in research studies on designing how to implement both methodologies as a single tool to rip the maximum value of the synergetic strength of both tool (Furlan et ., 2023; Lalmi et al., 2022). The integration of lean and agile can also be applied to project construction management in the context of total cycle time and lead times to reduce waste in predictable and unpredictable environments which helps to satisfy customer expectations responsively (Furlan et al., 2023; Lalmi et al., 2022; Manson-Jones &Towell, 1999). The total cycle time uses a lean approach while lead time uses an agile approach and the integration of both methodologies offers a unique efficiency and effectiveness regardless of any environment that no single approach can offer (Furlan et al., 2023; Lalmi et al., 2022; Manson-Jones &Towell, 1999).

2.7 Application of Lean and Agile in Health Care Industry

The application of lean and agile in the healthcare environment continues to be very significant as the population increases to diminish resources and public infection disease outbreaks continue to increase the complexities of patient healthcare management (Ali &Ali, 2024; Mishra et

al., 2018; Musau et al., 2015). The efficiency and effectiveness of healthcare professional responsibility to maintain zero quality defects continue to struggle as the healthcare landscape continuously expands with new medical demands (Ali & Ali, 2024; Mishra et al., 2018; Musau et al., 2015). Currently, the healthcare care environment of today is very dynamic and covered with uncertainties as the increasing population impacts resource efficiency, quality sustainability, and management of unpredictability of patient-changing needs (Ali & Ali, 2024; Mishra et al., 2018; Musau et al., 2015). Mishra et al., 2018 study acknowledged that the healthcare industries are struggling with systematic methods on how to implement lean and agile as a single tool. Moreover, Mishra et al., 2018 study held that healthcare services are intangible, perishables, inseparable, and heterogenous which requires customer interaction management requirement as a path to success. Also, Mishra et al., 2018 study recommended that healthcare services are perishable and it will be best to use lean and agile methodology to manage its supply chain process to fit patient changing needs. Mishra et al., 2018 study concluded that there is a need for the integration of various healthcare departments to achieve efficiency using lean methodology and effective responsiveness that manages uncertainties using agile methodology. Mishra et al., 2018 study acknowledged that the application of lean and agile can be helpful in the healthcare value chain system to manage make-to-stock and make-to-order perishable products that depend on a critical level. The implication of the Mishra et al., 2018 study is that the higher demand for a critical service or medication determines a make-to-stock or make-to-order supply chain strategy that supports demand cost efficiency and effectiveness to fit patients changing needs. Ali & Ali, 2024 acknowledge that the application of lean and agile offers a work environment that fosters connectedness among healthcare providers and supports sustainable healthcare practices that fit customer-changing needs. The increasing experience of uncertainties in the healthcare system requires a lean and agile application that offers adaptability to rapid continuous capacity change since healthcare services are perishable (Ali & Ali, 2024; Mishra et al., 2018; Musau et al., 2015). Ali & Ali, 2024 held that the application of lean and agile is a leadership concept that fits today's fast-paced, network evolvement and changing market environment. Moreover, Ali & Ali, 2024 study acknowledged that the application of lean and agile is specifically designed to support organizations to manage rapidly changing complex environments. Also, Ali & Ali, 2024 study held that the application of lean and agile prioritizes customer-centric value delivery that supports collaboration that increases efficiency and outstanding responsiveness for rapid change that fits patient changing needs. The dynamics of the healthcare environment show that uncertainties and demand change are inevitable considering its complexities, perishability and lean methodology alone can not manage uncertainties and higher complexities that only Agile methodology can manage (Ali & Ali, 2024; Mishra et al., 2018; Musau et al., 2015; Lalmi et al., 2022). Ali & Ali, 2024 study held that the application of lean and agile will be significantly

relevant when the need for rapid swift adaptation to change is necessary in any healthcare market environment. Several studies have shown that application of lean and agile continues to be a significant path toward innovation that can manage uncertainties and disruptiveness in any market environment to fit customer changing needs (Ali & Ali, 2024; Mishra et al., 2018; Musau et al., 2015; Lalmi et al., 2022). Ali & Ali, 2024 held that the application of lean and agile provides effective corporation, continuous improvement, adaptability, responsiveness, etc. that delivers value that fits patients changing needs. Ali & Ali, 2024 study concluded that the application of lean and agile provides high-quality care to patients and a sustainable healthcare system. Moreover, Li & Martins, 2024 study held that the application of lean and agile strategy suits the healthcare environment because the level of demand is unpredictable and the product is perishable. The study of Li & Martins, 2024 provides an example of the unpredictable and perishable nature of the healthcare environment using hospital emergency units that always require resource availability to responsively fit patient changing needs. The use of both lean and agile in health care offers an effective way to simultaneously achieve efficiency and effectiveness that provide the best quality care at the least cost (Ali & Ali, 2024; Mishra et al., 2018; Musau et al., 2015; Lalmi et al., 2022; Li & Martins, 2024). Also, Li & Martins, 2024 acknowledged that the application of lean and agile is still at the infancy stage in health care and further attention is required to invest in its impact on the healthcare system. The application of lean and agile continues to make waves in providing cost reduction, waste reduction, and responsiveness in handling uncertainties but a structured design process is lacking that will help the healthcare field to successfully reap the benefit of both tools without experiencing dilemmas (Furlan et al., 2023; Mishra et al., 2018; Lalmi et al., 2022; Li & Martins, 2024; Tamblin, 2024). The study by Li & Martins, 2024 held that the application of both lean and agile in supply chain management categorizes lean as upstream reducing waste to increase production efficiency while agile is downstream that satisfies volatile market demand responsiveness. The field of healthcare management inevitably involves supply chain management and for that reason, the application of lean and agile is significantly required to achieve efficient and effective healthcare value delivery that fits patients changing needs (Ali & Ali, 2024; Mishra et al., 2018; Lalmi et al., 2022; Li & Martins, 2024).

2.8 Application of Lean and Agile in Supply Chain Management Industry

Supply chain management is an inevitable process that is required during the production of goods or services that fit customer changing needs (Ahmed & Rashid, 2021; Hassan et al., 2020; Mishra et al., 2018). Hassani et al., 2020 study held that the implementation of lean and agile supply chain management will eliminate all kinds of waste and increase the capability of an organization to respond to uncertainties and market volatility successfully. The application of lean and agile in

supply chain management unveils the significant need to combine the two different methodologies as a single methodology to eliminate or reduce the effect of underperformance of new product development (Ahmed & Rashid, 2021; Hassan et al., 2020; Mishra et al., 2018). Supply chain management practice used in the production of goods or services is a significant process that is inevitable to avoid during customer value creation. Whether make-to-stock or make-to-order is used, no single methodology of either lean or agile can offer superior efficiency and effectiveness to eliminate underperformance during new product development (Ahmed & Rashid, 2021; Hassan et al., 2020; Mishra et al., 2018; Lalmi et al., 2022). The market environment of today continues to be unpredictable as technology evolves and globalization spreads to cause high-volume customization. These are significant determinants of customer changing needs that a single lean methodology or agile methodology can not handle efficiently and effectively but only a synergetic combination of both tools can manage it (Ahmed & Rashid, 2021; Furlan et al., 2022; Hassan et al., 2020; Mishra et al., 2018; Lalmi et al., 2022). Moreover, Hassan et al., 2020 study held that the application of lean and agile methodologies in supply chain management complement each other to offer a competitive advantage to an organization. The application of lean and agile in supply chain management enjoys a synergetic quality that helps in improving efficiency and responsiveness that eliminates product underperformance regardless of the market environment (Ahmed & Rashid, 2021; Furlan et al., 2022; Hassan et al., 2020; Mishra et al., 2018; Lalmi et al., 2022). Hassan et al., 2020 study held that the union of the concept of lean and agile is what resulted in the concept of leagility. The concept of leagility made it clear that the benefit of applying lean and agile as a single methodology in the production of goods or services offers a significant attractive benefit that every organization desires to rip these benefits although management of its complexity continues to stand a big challenging factor (Alshurideh et al., 2023; Ahmed & Rashid, 2021; Furlan et al., 2022; Hassan et al., 2020; Mishra et al., 2018; Lalmi et al., 2022). Hassani et al., 2020 study held that lean thinking in supply chain management eliminates all kinds of waste to offer operational efficiency while agile thinking overcomes the problem of uncertainty to customer high volume customization or demand that lean cannot manage. The synergetic quality of lean and agile helps the supply chain to work efficiently and effectively to achieve customer satisfaction and expectation regardless of the market environment (Ahmed & Rashid, 2021; Furlan et al., 2023; Hassan et al., 2020; Mishra et al., 2018; Lalmi et al., 2022). Hassani et al., 2020 study concluded that the application of lean and agile in the supply chain process helps to categorize the lean process with the agile process using a decoupling point. Moreover, Hassan et al., 2020 held that the decoupling point offers a strategy that limits the magnitude of uncertainties on customer orders in the supply chain process and this strategy offers higher efficiency and effectiveness that achieves customer satisfaction and expectation. The decoupling point is the buffer zone between fluctuating customer orders and smooth production

process output that helps to provide information on value-added differentiation that satisfies customer demand (Ahmed & Rashid, 2021; Hassan et al., 2020; Mishra et al., 2018). Hassan et al., 2020 study also held that the decoupling point concept is linked up with upstream activities (lean) and downstream activities (agile) that offer customer satisfaction and expectation.

Also, Hassan et al., 2020 study held that the customer decoupling point from a combination of lean and agile applications in the supply chain provides strategic information for an organization to strike a balance between market demands and resource capabilities. The need to use a combination of lean and agile to strike a balance between market demand and resource capabilities helps an organization to manage uncertainties that only one methodology can not manage but both lean and agile combination (Ahmed & Rashid, 2021; Hassan et al., 2020; Mishra et al., 2018). Hassani et al., 2020 study held that the decoupling point can be applied in the context of make-to-stock and make-to-order, which helps to manage demand fluctuation. The Hassani et al., 2020 study showed that using both lean and agile can be applied in several contexts such as push and pull strategy to increase efficiency and effectiveness that only one methodology can not offer. The benefit of using lean and agile in supply chain management can also be used in the context of total cycle time that improves efficiency through waste reduction and agile in the context of lead times that offers just-in-time delivery that satisfies customer satisfaction and expectations (Ahmed & Rashid, 2021; Hassan et al., 2020; Mishra et al., 2018; Lalmi et al., 2022). The study from several scholars in different disciplines continues to show that the benefit of embracing the application of lean and agile as a single methodology in different organizations outweigh the fear of its complexity and unwillingness to invest research study on how to design a systematic process for a hybrid application (Ahmed & Rashid, 2021; Furlan et al., 2023; Hassan et al., 2020; Mishra et al., 2018; Lalmi et al., 2022). Ahmed & Rashid's 2021 study held that the combination of organizational factors and environmental uncertainties decreases the predictability of performance in supply chain management which increases risk. Moreover, Ahmed & Rashadi, 2021 study showed that the inevitable presence of uncertainties impacts the ability to predict the market environment and this situation can only be solved by using both lean and agile combinations that can adapt to any type of market environment. Ahmed & Rashadi, 2021 study held that the application of lean and agile offers resilience and robustness that help supply chain decision makers to identify the de-couple point with the right methodologies. The benefit of resilience and robustness helps to create a significant strategic level that efficiently and effectively manages all forms of supply chain management disruption (Ahmed & Rashid, 2021; Hassan et al., 2020; Mishra et al., 2018). The application of lean and agile methodology continues to play a significant role in supply chain management and is an inevitable activity required for efficient and effective production of goods and services that fit customer

satisfaction and expectations regardless of environmental constraints (Ahmed & Rashid, 2021; Furlan et al., 2022; Hassan et al., 2020; Mishra et al., 2018; Lalmi et al., 2022).

2.9 Lean and Agile Skepticism on Today's Market Environment

The combination of lean and agile as a single methodology in the production of goods or services continues to be at the infancy stage in most organizations since its introduction in the 1990s as a result of skepticism and its complexities during implementation (Alshurideh et al., 2023; Ahmed & Rashid, 2021; Furlan et al., 2022; Hassan et al., 2020; Mishra et al., 2018; Lalmi et al., 2022; Tamblin, 2024). Moreover, most organizations apply lean and agile applications to their organization production process based on their experience, resources, and strategic business target constraints (Alshurideh et al., 2023; Ahmed & Rashid, 2021; Hassan et al., 2020; Mishra et al., 2018). The fact that there is no existing systematic standard process that an organization can follow to tailor their lean and agile methodology combination to rip the full benefit of the synergetic advantage of the two methodologies creates a great challenge of fear that results in skepticism (Furlan et al., 2022; Hassan et al., 2020; Mishra et al., 2018; Tamblia, 2024). Tamblia, 2024 study held that business leaders used a different approach in making a product decision and technology transformation that depends on a shared knowledge of their team on the potential of what the product can offer. The leadership that exists in every organization contributes to its embracement of the use of lean and agile methodology because the experience and interest of the leadership team impact readiness to invest in research and development on an innovation (Tamblia, 2024). The organizational leadership structure creates internal skepticism towards advocating or adopting an innovation such as lean and agile combination methodology (Tamblia, 2024). The magnitude of the complexity is a factor, but the human factor outweighs the complexity factor particularly when there is uncertainty because innovation requires interest, embracement, acceptable certainty level and great investment that focuses resources toward a result-oriented research development (Larsson & Ratnayake, 2022; Tamblia, 2024). The lean and agile implementation failures have caused many organization's financial dilemmas to be skeptical about investing effort and resources to understand how lean and agile methodology can collaborate to rip the synergetic benefit of both tools as a single methodology (Furlan et al., 2023; Larsson & Ratnayake, 2022; Tamblia, 2024). Therefore, Continue usage of unstructured methodology creates greater complexity and uncertainty that most organizations cannot afford to take and such risks with a high probability of accident that creates a path to production dilemma/regrets that always leads to skepticism (Larsson & Ratnayake, 2022; Tamblia, 2024). Skepticism only manifests among leaders when there is uncertainty and unstructured methods during production management (Larsson & Ratnayake, 2022; Tamblia, 2024). Tamblia, 2024 study hinted that in most cases, leaders of organizations entrust more to their team without being aware that

sometimes that team might not understand how best to align daily work activities to deliver organizational business goals. Tamblin, 2024 also reveals that the mindset of the leader and its team structure towards openness to advertise and welcome new business or technological ideas from other employees outside the designated team helps to increase the organization's knowledge management strategy toward innovation adaptation. Moreover, many small organization have attributed their dilemma of not using lean and agile methodology as a single tool to a lack of finance to invest in both lean and agile software that only organizations with big economic resources can invest in (Tamblin, 2024). This study welcomes the fact that finance is among the factors but the greatest factor among all of them is the leadership strategy and its organizational team structure to create an enabling environment to invest in knowledge management that will offer the exclusive benefit of erasing skepticism. Maihotra, 2004 study recognized that human input plays a significant role than technology or financial capital during knowledge management. Moreover, the reason why most organizations are skeptical is because of a lack of leadership resources and motivation to invest in research development to find how to apply lean and agile as a single tool will offer benefits that outweigh the research resource requirement because financial institutions are always available for investors. The principal investigator, the research supervisor, and the Durban University of Technology Engineering graduate school have overcome the skepticism through our excellent leadership and openness to knowledge management that helped to support the investigation on how to integrate the application of lean and agile as a single tool. The synergetic tools of lean and agile intend to manage the problem of product under-performance experience in a new product life cycle that either a single lean tool or agile tool can not manage. Several studies have shown that the benefit of combining lean and agile as a single tool outweighs the skepticism. Therefore, continue usage of unstructured methodology creates greater complexity that most organizations can not afford to take such risk with a high probability of uncertainty that creates a path to production dilemma (Tamblia, 2024). Furlan et al., 2023 study highlighted that there is a need for research investment to find how to apply lean and agile methodology as a single tool so that an organization can rip the immense synergetic benefit of these combinations. Tamblia, 2024 study hinted that the size of a company has a significant impact on the ability of the organization to embrace lean and agile applications as a single methodology because there will be a lot of resistance from different departmental employees and increased resource requirement availability. These resistances experienced in most organizations can be managed depending on the leadership operation strategy, the organization structure, and the knowledge management approach adopted in the culture of the firm (Tamblin, 2024).

2.10 Management of Skepticism on Application of Lean and Agile Method

The review of the problem of lean and agile application studies shows that a skeptical mindset due to lack of systematic structure in existence is among the most challenging issue that has to be managed (Larsson & Ratnayake, 2022; Tamblin, 2024). This is an important fact that needs to be strategically managed to help the advancement of lean and agile applications as a single tool to fit the speed of technology change. The speed of technology innovation increases the volume of customization which is among the causes of product underperformance during its life cycle (Vallon et al., 2015; Varl et al., 2020). Larsson & Ratnayake, 2022 study held that a lean and agile mindset is an enabler towards the improvement of a workplace culture, quality, and productivity output of a project team. The mindset of a project team regulates its level of skepticism toward adopting lean and agile applications in its organization process (Larsson & Ratnayake, 2022). The management of skepticism of the application of lean and agile in this study used the strength, weakness, opportunities, and threats (SWOT) analysis of an organization during the process of either make-to-stock or Make-to-order or both. The SWOT analysis was used to conduct a holistic review that will support a strategic recommendation that improves the mindset of organization executives (Larsson & Ratnayake, 2022). Larsson & Ratnayake, 2022 study held that the industries are experiencing an industrial revolution that requires structural flexibility to adapt to changes that support competitiveness. The current impact of technology innovation as digitalization grows makes change an inevitable process, and it makes skepticism an unavoidable experience (Larsson & Ratnayake, 2022; Tamblin, 2024). The study considers the management of skepticism towards the application of lean and agile in an organization to support the new research development outcome, on how to systematically apply lean and agile methodology as a single tool. Moreover, Larsson & Ratnayake, 2022 and Tamblin, 2024 studies held that there is always disagreement on whether lean methodology and agile methodology are mutually supportive or mutually exclusive among organization leaders, which delays its synergetic application. Many leaders in high-performing organizations use different strategies towards make-to-stock and Make-to-order, which is the leading cause of most disagreement of either lean or agile method because different levels of risks are involved. The changing speed of innovation creates an inevitable need for both approaches to be used as a single method to manage product underperformance during its life cycle (Larsson & Ratnayake, 2022; Tamblin, 2024). The use of lean and agile applications in an organization offers flexible planning design, waste reduction, quality management, and customer-changing requirements (Lalmi et al., 2022; Larsson & Ratnayake, 2022; Tamblin, 2024). Larsson & Ratnayake, 2022 study held that internal factors can be categorized as strengths and weaknesses in terms of SWOT analysis while external factors can be classified as opportunities and threats. The study delves into what kind of internal factors, and external factors can create skepticism on a firm to move forward in adopting the application of lean and agile as a single methodology in an

organization. Also, Larsson & Ratnayake, 2022 study held that the strengths and weaknesses of an organization are controlled by the organization because it is internal. Also, these internal factors consist of resources and capabilities such as finance, technical, or product life cycle. Moreover, Larsson & Ratnayake, 2022 study concluded that the opportunities and threats of an organization are not controlled by the organization because it is external, and they consist of technology change, competition, social trends, rules, and necessary regulations. The use of SWOT analysis helps to have a holistic review of key internal and external factors that help both organization executives to align company strategy with the market situation during the adoption of lean and agile application decisions (Larsson & Ratnayake, 2022).

The study review on the application of lean and agile as a single methodology found that most executives will face skepticism on whether the strength of the organization has effective know-how to adopt the integration of lean and agile approach that will bring assured internal benefit to the organization before its adaptation (Larsson & Ratnayake, 2022 and Tamblin, 2024). The study through its critical review determines that a logical approach to managing skepticism on the strength of an organization to adopt lean and agile as a single tool depends on the leadership's ability to motivate and invest in knowledge management that will strengthen research development to test relevant research outcome alignment with the company internal factors such as human resources etc. (Larsson & Ratnayake, 2022 and Tamblin, 2024). Moreover, the study review on the application of lean and agile as a single methodology found that most executives will face skepticism on whether the weakness of the organization is limited by not having the required resources to manage a systematic design of lean and agile application from any research study that can be remodeled to align the organization business model that offers internal benefit (Larsson & Ratnayake, 2022 and Tamblin, 2024). The study determined that a logical approach must be used in managing skepticism on the weakness resulting from limitations to adopting lean and agile as a single tool, which depends on the leadership's ability to transform limitation into strategic advantage by investing in different kinds of resource procurement through educational training support (Larsson & Ratnayake, 2022 and Tamblin, 2024).

The study review on the application of lean and agile as a single methodology found that most executives will face skepticism on whether the external opportunities available are enough to offer a positive effect that can increase customer satisfaction and expectation that will ignite high-profit revenue realization for the organization within its market environment (Larsson & Ratnayake, 2022 and Tamblin, 2024). The study recommends that a logical approach is necessary to manage skepticism during forecasting the positive or negative impact of threats during the application of lean and agile as a single methodology. The study determines that the integration of lean and agile in an organizational process depends on the leadership foresight and openness to innovation

adaptation that supports the sustainability of the new technology management (Larsson & Ratnayake, 2022; Tamblin, 2024). The path to sustainability provides a rational forecast mechanism and a continuous improvement mindset that overcomes skepticism and transforms opportunities into success (Larsson & Ratnayake, 2022; Tamblin, 2024). The study also found that executives will face skepticism on whether the external threats that exist in their market environment have the potential size to impact their success considering the market investment required to adopt lean and agile into the organization (Larsson & Ratnayake, 2022 and Tamblin, 2024). The study determines that a logical approach to managing skepticism to understand all the threats depends on leadership interest in knowledge management to invest in market research and business product life cycle modeling to identify all possible threats that an organization will experience when lean and agile methodologies are not implemented (Larsson & Ratnayake, 2022 and Tamblin, 2024).

In conclusion, the study takes into consideration the issue of skepticism towards the application of lean and agile to craft a systematic approach that helps to direct organizations on how to combine lean and agile as a single tool. The systematic design in this study uses the concept of lean manufacturing and blue ocean manufacturing to provide a step-by-step approach to integrate lean and agile as a single method (Sadiq et al., 2021; Sushil & Dhir, 2024). The systematic design combined ScrumLeansix Sigma where Scrum is an agile tool and Lean Six Sigma is a lean tool. The combination of the lean and agile tools mentioned above was used in selecting lean and agile processing factors that support new product development of temperature manufacturing equipment. Moreover, the systematic design also takes into account that the impact of digitalization is inevitable, and it is a continuum process as technology innovates, which is a threat to the product underperformance during its product life cycle without a sustainability strategy (Larson & Ratnayake, 2022; Sadiq et al., 2021; Sushil & Dhir, 2024; Tamblin, 2024). The study develops a six-action step-by-step approach that consists of value identification & Mapping, value feedback control, Value flow Pattern design, Value deployment, Value Review Assessment, and new product launch. The six systematic approaches and their testing will be discussed in greater detail in subsequent chapters.

2.11 Summary of the Study chapter

Chapter two focuses on the literature review of the study with emphasis on brief literature review, lean manufacturing, Agile manufacturing, and the need to apply lean and agile processes. Chapter two strives to review relevant literature that has contributed significantly to the study. Chapter two also reveals the gap between this study and the previous existing study to show the unique relevancy of this study to alleviate humans from its current problem of underperformance in new product development. Chapter two literature reveals that the problem that the study is trying to solve has not

been solved to this date which helps to strengthen the relevance of the study. Chapter two of the study found that there is a need to find how to integrate lean and agile into product development so that the synergies that exist between them can be generated and utilized to increase efficiency and effectiveness. Moreover, it is quite clear to this date that there is no method to integrate lean and agile exists, which is the leading cause of underperformance experienced by most firms.

RESEARCH DESIGN AND METHODOLOGY**Introduction**

The research study intends to show how to integrate lean and agile as a single tool that will help to eliminate waste to improve the underperformance problem that firms are suffering in today's market environment in managing high-volume customization that will continue to increase as globalization and technology evolves (Furlan et al., 2023; Varl et al., 2020). The research will use the synergetic application of lean and agile processes (robustness and smartification) as a single tool using process integration of lean manufacturing modelling and blue ocean engineering to develop six action frame work. The six action framework will investigate on how to eliminate all forms of waste that inevitably exist during new product development that fits all customer-changing requirement. The impact of the unending speed of globalization and technological evolvement have made customer-changing requirements among the most complex and relevant driving forces in new product development that satisfy the product life cycle strategy of a firm (Andersen, 2022; Andersen et al., 2023; Varl et al., 2020). The problem of waste in production continues to be an inevitable experience during new product development, and this study aims to tackle this problem so that firms will stop experiencing the problem of underperformance which is the leading cause of most firm extinction.

3.1 Research Procedure and Methodology

The research procedure will use platform-based product development to show the integration of lean and agile in a production process that involves manufacturing a temperature measuring tool used in a hospital setting. The study focuses on how to apply lean and agile processes in new product development, and this is why the study selects platform-based product development that is suitable for any production process rather than discrete product development. The study intends to use the synergy that exists between lean and agile (robustness and smartification) to overcome the effect of waste that causes underperformance of products that is currently experienced during new product development. Moreover, the study also chose platform-based product development because it is suitable for a process that is continuous, flexible to change, and allows batch production manufacturing which is currently used by several global manufacturers (Andersen et al, 2022). Additionally, the choice of platform-based development is because it offers the advantage of balancing internal complexity against external complexity which helps to provide an efficient competitive advantage that adds value that fits customer-changing requirements

(Andersen, 2022). Also, platform-based product development offers increased flexibility, and utilization of production facilities resources, improves product quality, reduces waste, increases efficiency, and reduces costs in manufacturing, and inventory management (Galizia et al., 2020; Andersen, 2022; Ulrich et al., 2020). Additionally, platform-based development also influences product development activities by increasing the rate of innovation and reducing the testing rate (Ulrich et al., 2020). The methodology of the study will focus on identifying temperature manufacturing equipment activities that are relevant in the product platform-based development stages starting from set up to final delivery of the product to the end user. Technically, all aspect of new product development starts with setting up product architecture platform-based product development which determines the configuration and interaction of individual elements of the product, and this comprises modules that encompass the entirety of the function (Andersen, 2022). The method on how integrating lean and agile in this study considers two forms of manufacturing strategy which are make-to-order (pull) and make-to-stock (push). The study used ScrumLeanSix sigma to identify the significant process factors where scrum is an agile tool that manage unstable activities and lean six Sigma is a lean tool that manage stable activities. The study methodology will use six action frameworks in a systematic step to manage all activities relevant to the product platform-based development process of temperature equipment manufacturing. The six systematic processes will be detailed and explained below to show how lean and agile can be successfully integrated to manage the two inevitable two forms of waste that cause underperformance of new product development to this date. The six steps are as follows.

Step one: Value Identification and mapping

The platform-based product development starts with a platform-based development architectural setup. The study will use integrative lean tool and agile tool process through automated value stream mapping to identify all the set-up process activities that are relevant in a product architecture design that will be used in a platform-based development of temperature manufacturing equipment used in a hospital setting. The activities will consider two production strategies make-to-order activity (pull) and make-to-stock activity (push) in a platform-based development. The reason for this consideration is that different market segment requires different production strategies, and every successful firm competitively uses both production strategies in different market environments although make-to-order stands out to fit customer-changing requirements as mass customization continues to be the most competitive trail of the 21st century. The study considered the following relevant activities as factors/variables during new product development of a temperature measuring instrument which includes procurement cost, procurement time, assembly cost, assemble time, information flow cost, information flow time, Manufacturing cost, work in process, material flow

cost, testing cost and product delivery. The product architecture starts with a setup for platform-based development during new product development for the manufacture of a temperature measuring instrument which is expected to have at least a minimum of eleven relevant activities which are considered as factors/variables as mentioned above. The use of lean and agile tools automated value stream mapping helps to remove two types of waste that come from the lean process which are cycle time and waste from the agile process which leads to responsiveness time. The study focuses on managing the inevitable waste that exists in make-to-order and make-to-stock by integrating lean and agile into the design setup to reduce waste to zero total cycle time from the lean process and zero lead time from the agile process. The integration of lean and agile makes the product development architecture very robust in identifying and removing all possible forms of waste during the product development setup, which is usually a complex process.

Step Two: Value Feedback Control

Step two requires that every product-based architecture platform has a permanently embedded smartification tool to successfully help manage high-volume customization of the value chain creation process that uses both internal and external resources to fit customer-changing requirements. The complexity of value chain creation results in highly changing turbulent effects as the volume of mass customization continues to increase during virtual market interaction. The second stage requires a flow of information and new materials that fit customer-changing requirements based on market knowledge through virtual corporations to exploit all new profitable opportunities in a volatile market. The feedback control helps to cancel out cycle waste and lead waste that inevitably exist during value creation customization as volume increases. Additionally, competitive value creation suffers two forms of waste that exist in this stage which involve cycle time and lead times during the flow of information and material to fit customer-changing requirements which is the leading cause of underperformance of product to fit customer-changing requirements. Moreover, the use of smartification tool provides excellent robustness that helps to remove these two forms of waste while fitting customer-changing requirements. Agility manages the rapid responsive forward and backward flow of information and new materials resources that fit customer-changing requirements based on market knowledge through virtual corporations to exploit all new profitable opportunities in a market segment. Agility regulates the value creation responsiveness that regulates the feedback control stage.

Step Three: Value Flow Pattern Design

The third step recognizes a clear logic that there is an inevitable flow of created value which impacts overall product value chain dynamics during new product development as the volume of

customization changes to fit customer changing requirements. The result of high incremental mass customization has different value flow patterns based on the level of environmental resistance, complexity, and volume of customized value creation that exist during a network of information flow and material flow which will be identified by the automated feedback control. The non-readiness to overcome modification or change in flow pattern during value creation to fit customer-changing requirements creates lean waste in the form of cycle time and agile waste in the form of lead time which is among the leading factors for product underperformance. The use of automated smartification helps to manage both laminar market flow and turbulent market flow demand patterns that result from incremental mass customization to fit the customer-changing requirement. The use of automated smartification changes the effect of flexibility requirement which is slow in its market flow compatibility offering to robust flow that improves all forms of value flow patterns on the flow of information, and other material resources to eliminate all waste to achieve total zero cycle time and zero lead time. Moreover, the value flow pattern plays a relevant role in managing customer-changing requirements because inefficient value flow creates a lot of uncertainties and complexity that delay the velocity of value creation to fit customer-changing requirements, and it is the leading cause of waste that leads to product underperformance. The inefficient use of lean and agile tools in value flow management continues to be among the leading causes of waste that lead to product underperformance, obsolescence, and abandonment causing most firms to suffer extinction.

Step four: Value Deployment

The fourth step requires that all resources and created values be put into action to produce a finished product that aligns with customer-changing requirements, and the finished product will be launched for market introduction. There is a lot of waste involving cycle time and lead time during the flow of resources to the manufacturing process and finished product to market introduction to create delivery to customer location. Regardless of the production strategy of either make-to-order or make-to-stock, there is a huge form of waste in the form of cycle time from a lean process perspective, and there is also waste in the form of lead time from an agile process perspective. This stage requires automated smartification that will remove all waste in the manufacturing process by providing a robust responsive structure that will remove all forms of product in process and all logistic bottlenecks during resource flow into production and finished product into delivery to the customer. Moreover, the final product delivered to the market requires an automated smartification with an embedded feedback control information system that creates visibility for the product development managers to view all process progress on the temperature manufacturing product. The use of feedback smartification helps to send signals to the product development team on product performance functionality, customer complaints, and all constraint experiences during all processes

to customer use. Additionally, Smartification helps to create a robust responsiveness that fits customer-changing requirements which helps to quickly redefine the product life cycle and eliminates waste by preventing the product from experiencing obsolescence, redundancy, and underperformance in its market environment. Most firms have the greatest problem during value deployment that fits customer changing requirements, and this is why some product tends to fail before market launch, and some fail shortly after market launch which causes a lot of profit loss to the firm that causes extinction.

Step five: Value Review Assessment

This stage requires an automated review of feedback information from the value deployment stage on customer complaints, satisfaction, and product automatic performance metrics embedded in the product. The product development team will have to review the information on customer experience, product functional performance, and product life cycle. The team will assess the impact of duplication on its created value by competitors, and alternative strategy to elongate duplication. The team will apply a transient strategy to create new values based on information flow and resources from the value deployment stage to create uncontested market space to secure a new sustainable competitive advantage. The use of smartification to conduct value deployment outcome review assessment makes the team enjoy the robust responsive flow of information and other resources that cut down several processes that support transient strategy to quickly create new values that satisfy changing needs. A lot of waste exists in this stage in the form of cycle time, which is a lean process and lead time, which is an agile process regardless of whether a firm uses make-to-order or make-to-stock.

Step 6: New Product Lunch

This stage is very relevant because it helps to cut the production process time which helps to redefine the product life cycle to frustrate the effort of competitors using duplicative strategy by creating new product value that will be ready for lunch as the product reaches its maturity stage. The value review assessment prepares a new value while the product life cycle is in the maturity stage which helps to sustain competitive advantage against duplicators because it creates robust uncontested market space while the product is in a maturity stage. The synergy of robustness and smartification helps to create a total zero cycle time and zero lead time so that the product will not suffer a declining product life cycle that causes a lot of waste because of obsolescence, abandonment, and underperformance. Agility redefines the product life cycle by creating uncontested market space that offers sustainable competitive advantage. The redefinition of product life cycle creates path for new product development.

3.2 Research Paradigm

The research will use the quantitative method of designing experiments with an emphasis on the Taguchi method. The research will also use quantitative statistical engineering based on values used as factors which can be used as quantifiable variables to support the hypothesis proposed in the study. The study will use Taguchi's orthogonal design, parameters design, and others including descriptive, correlation, or inferential statistics such as ANOVA, regression analysis, etc. Moreover, the study focuses on quantifying the impact of the synergetic quality of lean process in managing zero total cycle time, and agile thinking in managing total lead times during new product development that fits customer-changing requirements. The research study will use the design of an experiment using the Taguchi approach to reduce cost and increase both the validity and reliability of the study (Danisman et al., 2023; Khalaf et al., 2020; Titu et al., 2018). The Design of the experiment is a statical technique that studies the effects of multiple factors/ variables simultaneously (Khalaf et al., 2020; Khalaf et al., 2021; Titu et al., 2018).

3.3 Research Design

The study research design and methodology will use the idea of synergetic quality integration of lean and agile processes into a product development process to satisfy every phase of engineering design (Danisman et al., 2023; Khalaf et al., 2020; Khalaf et al., 2021; Titu et al., 2018). The study selected scrum lean six sigma (SLeSS) integration. Scrum is an agile tool and Lean Six Sigma is a lean tool. The research study focuses on using the application of lean and agile processes in the new product development process on a temperature measuring tool with emphasis on two production strategies (make-to-order and make-to-stock). The study will build quality in the product by integrating lean and agile that removes the inevitable waste that exists in the form of cycle time and lead time to overcome the issue of underperformance in new product development that affects the present global market environment (Olivera et al., 2022; Khalaf et al., 2021; Varl et al., 2020; Tyagi 2015). The study will use eleven selected factors /variables based on the integration of lean and agile to verify the relevance of the application of lean and agile in a manufacturing process. The research study aims to show that a new product has better quality when both tools of lean and agile are used during new product development than when a single tool of either lean or agile. Moreover, the determination will use the holistic comparison of the data results from using only lean process, only Agile process and integration of both lean and agile data to show that applying both tools together removes all forms of waste than either single tool. The study aims to show that using both lean and agile offers a robust product that can adapt to both stable and unstable market environments (Danisman et al., 2023; Varl et al., 2020; Tyagi et al., 2015). Moreover, the use of graphical

interaction from the Taguchi tool approach will help to support the data comparative analysis, and the ANOVA will show the multiple variances comparative study analysis (Danisman et al., 2023; Spatz, 2019; Tyagi et al., 2015).

3.4 Descriptive of Research Study Design

The research design was structured based on the application of lean and agile manufacturing processes in new product development to manage zero total cycle time and Zero lead time using Taguchi quality engineering phase breakdowns such as system analysis, parametric design, and tolerance design (Danisman et al., 2023; Khalaf et al., 2020; Khalaf et al., 2021; Titu et al., 2018). Moreover, the system analysis phase deals with how to combine many factors simultaneously. The parametric design phase deals with how to improve performance by adjusting factors without incurring value-added costs (Danisman et al., 2023; Khalaf et al., 2021; Titu et al., 2018). The tolerance design phase determines the control characteristics for each factor level that was previously identified concerning costs (Danisman et al., 2023; Khalaf et al., 2021; Titu et al., 2018). Moreover, the impact of globalization and technological evolution has continued to cause a high volume of customization that continues to transform the most stable market environment into an unstable market, and it is the leading cause of underperformance of new product development as the volume of customization increases which is the concern of this study (Varl et al., 2020; Womack et al., 2007). The research design was crafted to integrate the lean thinking process and lead times thinking process during new product development to remove all forms of waste and inefficiencies that will inevitably exist in both the production strategy of make to order and make to stock which is used by every successful firm at different circumstances. This research design considers only a case of new product development of a temperature measuring instrument used in a hospital setting as a practical case study although the methodology can be applied to both manufacturing and service industries if it uses process design in its value creation to fit customer changing requirements. Also, the research design was based on the application of the lean and agile methodology that will use eleven selected factors/variables of interest with two levels that utilize synergetic quality integration improvement of lean and agile tools (robustness and smartification) that offer both efficiency and effectiveness than a single tool of either lean or agile. The study of new product development utilizes market knowledge of customer needs, changing customer requirements, and virtual corporations to identify profitable market opportunities in a volatile market environment (Varl et al., 2020; Mansion-Jones and Towill, 1999). The selected factors/variables for quality integration improvement will be studied during new product development and, this will consist of lean thinking processes and the lead time thinking process. Moreover, the lean thinking process manages the zero total cycle time, and the agile thinking process manages the zero-lead time such that the integration

of both tool achieves the best efficient and effective new product development process that a single tool does not offer (Mansion-Jones and Towill, 1999; Oliveira et al., 2022; Tyagi et al., 2015). The research study design utilizes six systematic methodologies that consist of both lean and agile applications to manage the eleven selected factors using the synergetic quality of robustness from the lean process and smartification from the agile process to eliminate all forms of waste that cause inefficiencies during new product development (Mansion - Jones and Towill, 1999; Oliveira et al., 2022; Tyagi et al., 2015).

3.4.1 Design of Experiment

Design of experiment (DOE) is a technique used to study factors/variables simultaneously and most economically (Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021). Moreover, DOE helps a researcher to study the effects of individual factors on the results which helps to produce the best factorial combination to be applied to product or process design to obtain the best design among many alternatives (Danisaman et al., 2023; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021; Titu et al., 2018). The choice of using design of experiment (DOE) in this study was because it is highly effective wherever and whenever performance is part of the process controlled by more than one factor simultaneously (Danisaman et al., 2023; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021; Titu et al et al., 2018). Moreover, DOE is mostly applied by experimental hardware, but it is equally effective when applied to analytical simulation (Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021; Titu et al., 2018). In this study, the analytical simulation will be used instead of experimental hardware because of resource availability, and cost-effectiveness, and the method is equally effective in evaluating performance in the product design optimization of the new product development process (Danisaman et al., 2023; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021; Titu et al 2018). Generally, DOE applies to any situation that depends on many influential factors such as variables, inputs, parameters, etc. DOE is the best scientific option when a study has chances of many possibilities as outcomes when influential factors are simultaneously impacted (Danisaman et al., 2023; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021). The study will use eleven factors at two levels (2^{11}) to determine process performance in new product development using the synergetic application of lean and agile processes (Danisaman et al., 2023; Titu et al 2018). The research study will use the Taguchi approach which will allow only a small fraction of all possible conditions needed to be tested. Therefore, the DOE of eleven factors at two levels in the research study experiment will use an orthogonal array that requires twelve Taguchi experiments instead of 2,048 sizes of experiments in standard factorial design which makes the Taguchi approach more cost-efficient, time-effective, and robust to control signal to noise issues (Danisaman et al., 2023; Titu et al 2018; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021). The study can use any type

of DOE software, but the study will use the current model of the Qualitek 4 software manufactured by Nutek, Inc. to carry out the Taguchi analytical simulation on the selected eleven factors/variables at two levels. The study chose Qualitek 4 software due to its reliability, validity, and cost.

3.4.2 Taguchi Factorial Approach

The use of design of experiments was first introduced by Sir R.A. Fisher in England in the early 1920s with the primary aim of determining optimum water, rain, sunshine, fertilizer, and conditions needed to produce the best crop (Roy, 2001). Moreover, Sir Fisher laid out all combinations which were called treatments or trial conditions which are used in experimental studies (Roy, 2001). The use of DOE over time was transferred to industrial to measure the performance of many processes (Danisaman et al., 2023; Titu et al 2018; Kethley, 2008; Khalaf et al., 2021; Roy, 2001). Moreover, Taguchi DOE invented a special orthogonal array which helped to analyze the result of the experiments to determine the design solution that produces the best quality (Danisaman et al., 2023; Titu et al 2018; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021). Also, Taguchi invented a way to analyze results using a signal-to-noise ratio for analysis of repeated results which helps experimenters to easily ensure that a design is immune (robust) to the influence of uncontrolled factors (Danisaman et al., 2023; Titu et al 2018; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021). Perhaps, Taguchi DOE invented a loss function mathematical formula to compute the financial loss suffered when any aspect of quality does not fulfill the expected requirement which might lead to product dissatisfaction, all forms of waste, rejection, rework, and higher warranty cost, etc. (Danisaman et al., 2023; Titu et al 2018; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021; Roy, 2001). Taguchi DOE defined the loss function as the loss impacted on the public by a product quality starting from the time the product was designed and delivered to the customer which conforms around the target value with lower standard deviation in the outputs (Danisaman et al., 2023; Titu et al 2018; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021). Taguchi DOE highlighted that losses mostly come from the cost of production, functionality failure, maintenance and repair cost, design cost and rework, etc. (Danisaman et al., 2023; Titu et al 2018; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021; Roy, 2001). Also, Taguchi DOE highlighted that loss becomes the same as the cost of production of a single part, which is the cost of rejection, when all parts are made outside specification limits (Danisaman et al., 2023; Titu et al 2018; Fink and Gillet, 2006; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021). Taguchi DOE interpreted that the loss function still estimates loss even if parts are made within specification limits because it is necessary to allow the fact that a company might fulfill all specific limits but still have product warranty and customer complaints as a result of high volume customization of its product set (Danisaman et al., 2023; Fink and Gillet, 2006; Kethley, 2008; Khalaf et al., 2020; Khalaf et al., 2021; Titu et al., 2018).

Taguchi held that the loss function between the target and specification limits is a parabolic shape, symmetrical about the target which is shown in Fig 3.0 below (Danisaman et al., 2023; Titu et al 2018).

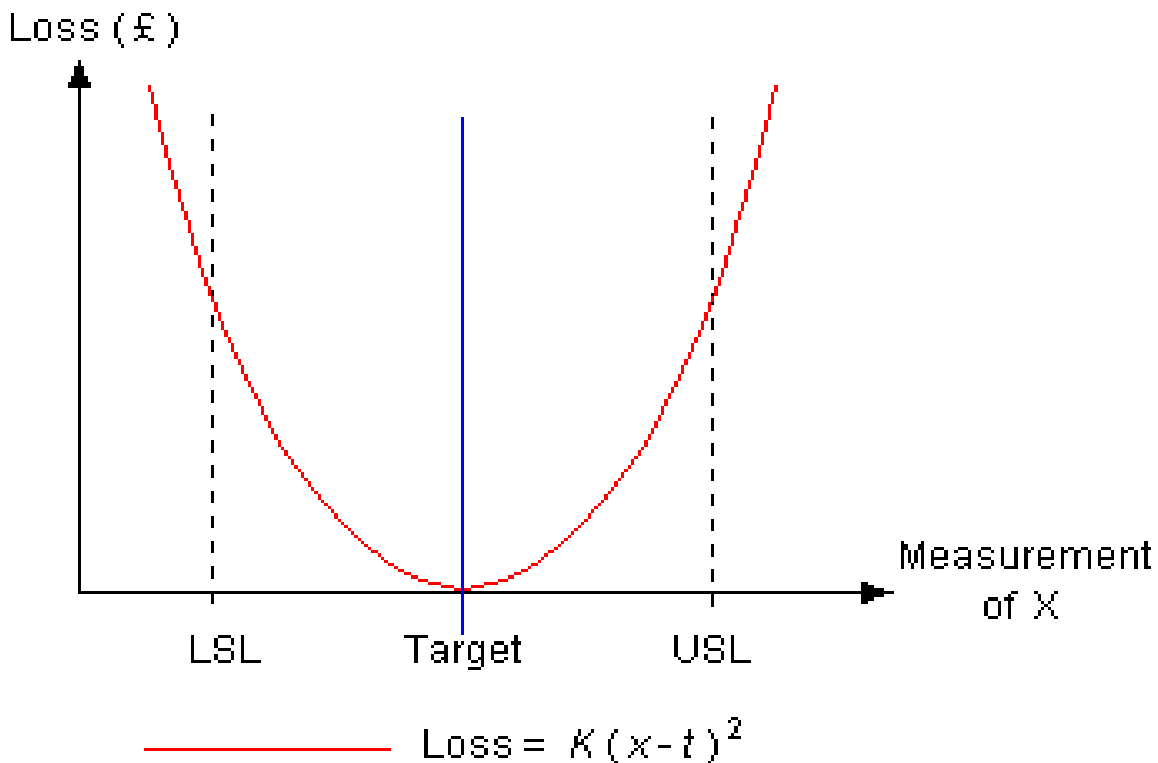


Fig 3.0 Taguchi loss function (Khalaf et al., 2020; Fink and Gillet 2006)

According to Taguchi DOE, there is an inevitable loss function resulting from customer complaints which is the cost of rejection when parts are made outside the specification limit. Therefore, this study adopts Taguchi's DOE loss function which is given as $Loss(y) = K(x-t)^2$, and $K = R/(USL-t)^2$ to calculate the financial waste that will result from cycle time and lead time as a result of not using both lean and agile during new product development when all part to be made are outside specification limits which is the leading cause of underperformance, obsolescence and abandonment as a result of customer dissatisfaction. Taguchi DOE lost function stated that $L(Y)$ = cost incurred when the characteristic y shifted from target (t) and, k is constant depending on the process, x = observed value of the characteristics X of a product or process parameter, t = target value or desired performance, LSL = Lower specific limit, USL = Upper specific limit, R = cost of rejection and K = cost coefficient representing cost of poor quality (Fink and Gillet., 2006; Khalaf et al., 2020; Khalaf et al., 2021). The above concept is a parameter design to make a process robust against environmental change (Khalaf et al., 2020; Khalaf et al., 2021).

3.4.3 Taguchi Engineering Simulation Analysis

The Taguchi DOE engineering analysis focuses on a robust design concept that produces reliable design during manufacturing and functional reliability of the product during use (Danisaman et al., 2023; Titu et al 2018). The Taguchi concept of robust design focuses on parameter control that regulates design to be strong so that it does not cause failure because of random “noise” (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). The Taguchi DOE robustness design held that a product or process tends to be controlled by several factors (signal factors, control factors, and Noise factors) depending on the desired response of concern by the investigator (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). The study of the integration of lean and agile considers signal factors to target the desired response while control factors produce a response depending on noise in the process and noise factors refer to random events in the process although mean and variance can be predicted but not controllable by the researcher/designer (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). The new product development of a human temperature measuring tool used in hospital settings involves Noise factors which consist of eleven factors/variables such as procurement cost, procurement time, assembly cost, assembly time, information flow cost, information flow time, manufacturing cost, material flow cost, work in progress, testing cost, delivery cost, etc., that cannot be controlled by the designer. The signal factors will be the integration of lean and agile tools as a single tool during new product development that provides a desired response. The control factors will be synergetic quality of Robustness and smartification which will respond based on noise factors in the process. The final response will produce a total zero cycle time and total zero lead time which will help to manage new products to eliminate the problem of underperformance that leads to product redundancy, obsolesce, abandonment, and possible extinction (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). Moreover, Fig 1.3 below shows an exemplary of Taguchi Robust design interaction of the factors, signal factors, control factor, and response.

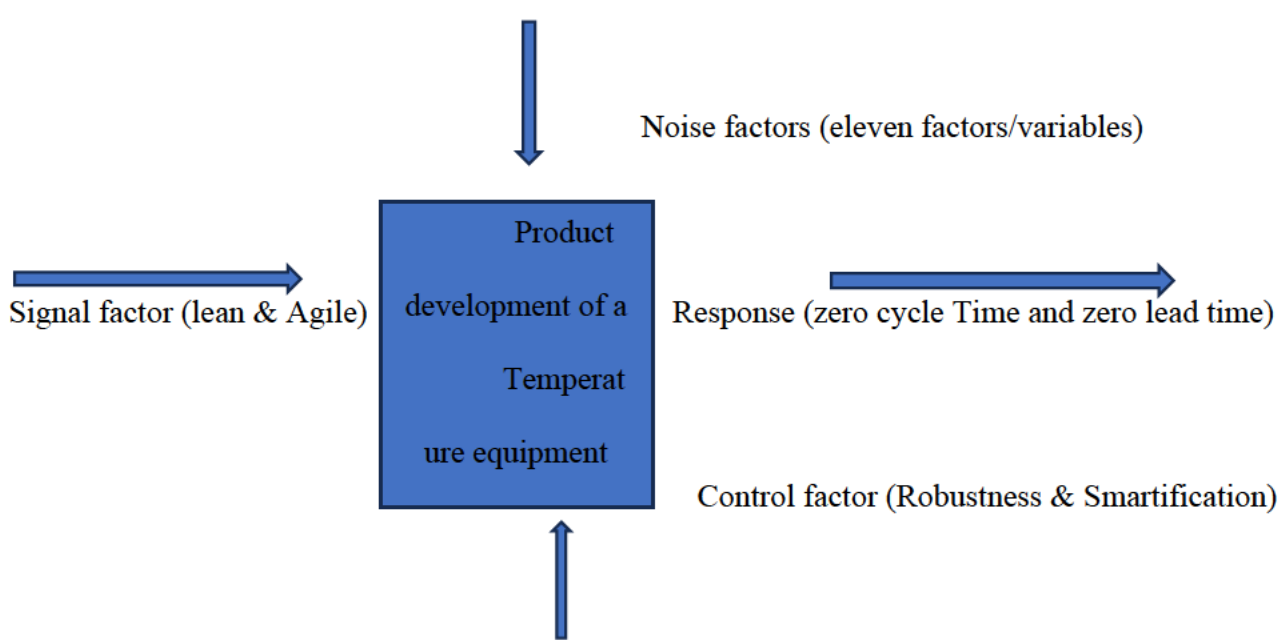


Fig 3.1 Taguchi Robust design of product development of Temperature equipment

The study will adopt the principle of Taguchi robust design analysis which focuses on three aspects which consist of concept design, parameter design, and signal noise (S/N) ratio (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). The concept design depends on competing technologies, customers, price, and other market forces that help to define quality in terms of customer requirements that help firms to produce high-quality products with low production costs (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). The parametric design identifies the control factors involved in the process to determine the optimal target of each participating factor to discover an efficient and effective process that supports robust design (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). The parametric design also optimized the response to reduce the noise. The study targets to adopt a parametric design to identify all signal factors and noise factors within their respective ranges and then select all the control factors along with their levels to design appropriate orthogonal arrays that will help to spot the main effect with a minimal number of runs (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). Moreover, the parametric design improves functionality by adjusting different levels of control factors. Therefore, to determine the signal-to-noise (S/N) ratio then we have that $k = S/N = 10 \text{ Log}_{10} 1/r (S_{\beta} - V_e) / V_N$ where r = measurement of the magnitude of the input signal, S_{β} = sum of squares of ideal function, V_e = mean square of nonlinearity, V_N = error term of linearity and nonlinearity (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). The Taguchi design parameter will be used in the study to calculate the performance of integration of lean and agile using the concept of signal-to-noise (S/N) ratio, and performance in most instances is better when its S/N ratio is smaller (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). The Taguchi S/N ratio relevant analysis reveals three types of S/N ratios, and it includes small best, highest best, and nominal best. The Small-best target value is when the target value of the performance characteristics y is zero then the signal/Noise ratio formula in the smallest-best case is given in equation 1 (Danisaman et al., 2023).

$$S/N = -10\text{Log} (1/10 \sum_{i=10}^n y_i^2) \dots\dots\dots \text{Equation (1)}$$

The highest-best value is when the target value is the largest. The target value of y is infinite, and the signal/Noise is given by equation 2 below (Danisaman et al., 2023).

$$S/N = -10\text{Log} (1/10 \sum_{i=10}^n 1/y_i^2) \dots\dots\dots \text{Equation (2)}$$

The nominal best value is when the certain target value is given as y and the value of mean and standard deviation becomes important to determine S/N and the equation is given below in equation 3 (Danisaman et al., 2023).

$$S/N = -10\text{Log} (\mu^2/\sigma^2) \text{ where } \mu = \text{mean and } \sigma = \text{Standard deviation} \dots\dots\dots \text{Equation (3)}$$

The study will use Taguchi orthogonal array design with a standard notation $L_n(I_m)$ where n= the number of experiments, I= number of levels, m= number of factors. The research study will use $L_{12}(2^{11})$ orthogonal design that will consist of 12 experiments using the Taguchi method instead of 2,048 full factorial standard experiments, two levels, and eleven factors to reduce cost, time and increase efficiency by providing a robust ratio of signal to noise effect. The Taguchi approach provides a graphical method technique to visualize the significant factors, which provides the best insight towards determining the optimum combination of factors and level of analysis (Danisaman et al., 2023).

3.5 Description of Research Factors and Variables of Interest

The study builds its factors/ variables by considering all the relevant activities that have a significant impact during new product development of temperature measuring equipment used in hospital settings which includes eleven factors such as procurement cost, procurement time, assembly cost, assemble time, information flow cost, information flow time, Manufacturing cost, work in process, material flow cost, testing cost and delivery product cost. Moreover, these variables consist of independent and dependent variables. Independent variables in this study consist of procurement cost, procurement time, assembly cost, assembly time, information flow cost, and information flow time. The selected dependent variables include manufacturing cost, work in process, material flow cost, testing cost, and delivery cost. The eleven selected factors/variables will be used to study the inevitable waste that exists during new product development of temperature measuring equipment which comprises of total cycle time from the lean process and lead time from the agile process. The study proposed that this waste problem can be corrected by using synergetic quality of robustness and smartification that exist during the integration of lean and agile into new product development. Moreover, the waste from cycle time and lead time is the leading cause of

inefficiency and ineffectiveness which is the leading cause of underperformance, obsolescence, and abandonment that causes extinction of most firms. The inevitable waste denies most firms the ability to timely create value that fits customer-changing requirements in a high-volume customized market environment of the 21st century.

3.5.1 Sample Plan Design

The sample design plan was based on the study objectives to integrate the application of lean and agile processes as a single tool in a new product development process. The list of factors/variables identified in the study have a relevant influence on the outcome of new product development activity simultaneously (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018). Moreover, the sample plan design used in this study is a DOE design with emphasis on Taguchi specifically designed with all two-level factors and interaction to manage zero total cycle time and zero lead time using DOE statistical software (QT4). The sample plan will use the Taguchi orthogonal array configuration of $L_{12} (2^{11})$ that will require only 12 experiments instead of 2,048 experiments with two levels and eleven (11) factors to run into QT4 DOE software. The study will also identify the factor/variable that most influences the strength using Taguchi analysis, graphical method, and careful examination of the last column of the ANOVA table. The process of identifying influential variable supports the Taguchi graphical method.

3.5.2 Sample Size Determination

The sample size was determined based on identifying a group of key factors/variables that influence the waste activities in the form of total cycle time and lead time during temperature measuring tools new product development process. The study selected eleven (11) factors/variables that consist of independent and the outcome is the dependent variables. The study used two levels (1 and 2) where level 1 will be designated as a low level with zero time where there is no waste from both lean and agile processes then level 2 will designate to be a higher level where there will be possible waste in either lean or agile process. Moreover, each of the factors selected contributes a significant effect during new product development. The Taguchi approach helps to reduce cost and time and enhances improvement in validity and reliability (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018).

3.5.3 Operationalization of Variables

The research utilizes operationalization to quantify factors/variables selected that tend to change the study outcome (Edmonds, 2018; Gonzales, 2021). Moreover, variables consist of

measurement property, logical implication, and theoretical construction of the idea under research study (Andrade, 2021; Edmonds, 2018; Gonzales, 2021). The operationalization of variables must not be only independent or dependent variables but must be both independent and dependent variables (Andrade, 2021; Edmonds, 2018; Gonzales, 2021). The operationalization of variables requires at least one independent and one dependent variable since one depends on the other (Andrade, 2021; Edmonds, 2018; Gonzales, 2021). Operationalization of variables uses four scales such as nominal, ordinal, ratio, and interval scales (Edmonds, 2018; Gonzales, 2021). The qualitative variables use nominal and ordinal while the quantitative variables consist of Intervals and ratios (Edmonds, 2018; Gonzales, 2021). The research study operationalization uses eleven factors/variables to set up its operation which consist of two levels where level 1 denotes zero or very low and 2 levels denote high or very sensitive increment. The phenomenon of operationalization helps researchers to superiorly define, measure, and reduce bias, improve validity & reliability, and enhance the subjectivity of variables under study to realize better decisions (Gonzales, 2021). The need for operationalization is relevant to this study to make the data robust and reliable with the least bias that improves the quality of performance in the selected study (Danisaman et al., 2023; Shojaei et al., 2021; Titu et al., 2018).

3.5.4 Statistical Method of data Analysis

The research study determines that the theoretical framework design is more compatible with the use of Taguchi method than standard design of experiment because of its reliability in managing complex continuous improvement processes and effective resource management. The study selected hospital temperature measurement equipment because it is a global product that is use globally to support human health management daily. The use of Taguchi method is very efficient, and effective in quality improvement, and this study is an improvement that focuses on removal of all waste in a manufacturing/production process to eliminate the problem of underperformance etc. The application of lean and agile integration can also be applied in service industry to support production management by cutting down waste in a system process (Alshurideh et al.,2023). Generally, this study can be apply to all aspect of human endeavor that utilize a process during it productivity (Furlan et al., 2023; Varl et al., 2020; Womack et al., 2007; Robertson & Jones, 1999). Moreover, all production process will inevitably experience cycle time and lead time although magnitude will be different based on environmental constraints (Furlan et al., 2023; Manson-Jones & Towell, 1999; Womack et al., 2007; Robertson & Jones, 1999). All production experience will experience under performance if a single lean or single agile is used because the inevitable waste that exist during production process requires synergetic removal that will eliminate product underperformance (Furlan et al., 2023; Manson-Jones & Towell, 1999; Womack et al., 2007).

Chapter three focuses on the research design and methodology of the experiment, Taguchi approach, Taguchi engineering simulation analysis, description of research factors and variables of interest, sample plan design, sample size determination, and operationalization of variables. Chapter three reveals why a quantitative approach using the Taguchi method was used to show how to systematically integrate lean and agile in new product development. Chapter three also discloses selected independent and dependent variables used to progress the study. Chapter three also discloses the criteria used in the research study design of the Taguchi method and its validity and reliability relevancy in the study. The study used eleven selected factors/variables to study inevitable waste that exists during new product development of temperature measuring equipment that comprises of total cycle time from the lean process and lead time from the agile process. The study stated it will use Taguchi orthogonal array configuration of $L_{12} (2^{11})$ that will require only 12 experiments instead of 2,048 experiments with two levels and eleven (11) factors to run into QT4 DOE software. The study will also identify the factor/ variable that most influences the strength using Taguchi analysis, graphical method, and careful examination of the last column of the ANOVA table. The process of identifying influential variable supports the Taguchi graphical method. The study selected scrum lean six sigma (SLeSS) integration. Scrum is an agile tool and Lean Six Sigma is a lean tool. The research study focuses on using the application of lean and agile processes in the new product development process on a temperature measuring tool with emphasis on two production strategies (make-to-order and make-to-stock). The study proposed to build quality in the product by integrating lean and agile that removes the inevitable waste that exists in the form of cycle time and lead time to overcome the issue of underperformance in new product development that affects the present global market environment (Olivera et al., 2022; Khalaf et al., 2021; Varl et al., 2020; Tyagi 2015).

DATA MANAGEMENT DESIGN & ANALYSIS**Introduction**

The data collection was based on using Taguchi DOE approach, which is a powerful statistical technique that improves product/process design (Danisaman et al., 2023; Shojaei et al., 2021; Roy, 2001; Titu et al., 2018). The study utilized Taguchi orthogonal design to achieve the highest degree of consistency in robust product and process performance to show a successful application of lean and agile manufacturing processes (Danisaman et al., 2023; Shojaei et al., 2021; Roy, 2001; Titu et al., 2018). Moreover, the idea of achieving a high degree of consistency in performance requires the management of uncontrollable factors such that the variability around the target is minimized (Danisaman et al., 2023; Shojaei et al., 2021; Roy, 2001; Titu et al., 2018). Also, uncontrollable factors called noise are the common source of variability during new product design manufacturing (Danisaman et al., 2023; Shojaei et al., 2021; Roy, 2001; Titu et al., 2018). The study selected eleven factors that will exist during the new product design development of Temperature measuring instruments used in a hospital setting. The selected eleven factors consist of both lean and agile activities. The study aims to successfully integrate lean and agile activities rather than using one tool of either lean or agile which is inefficient to reduce overall waste in the total cycle time and total lead time to achieve the highest degree of improved performance. The study will verify the possibility of successfully integration of lean and agile as a single tool by comparing the results of using a single tool of lean to manage lean activities, using a single tool of agile to manage agile activities, and using lean and agile tools to manage the entire activities that comprised of eleven factors. The study will use user-friendly software (Qualitek-4 (QT4) design and analysis of the Experiment by Taguchi method to investigate successful integration of lean and agile process

Moreover, Lean process alone will use the Taguchi orthogonal array, and it is based on the concept of Latin square using L8 (2^7) where 8 represents 8 trials, 2 represents two levels and 7 represents a seven-factor combination. The input data are automatically simulated by the software. Also, the Agile process alone will use the Taguchi array of L8 (2^4) where 8 represents eight trials, 2 represents two levels and 4 represents 4 factors although the four factors will have an empty column that will be automatically simulated. The lean and agile integration will use Taguchi's orthogonal array of L12(2^{11}) where 12 represents 12 trials, 2 represents two levels and 11 represents 11 factors which will be automatically simulated by the software. The study will use the outcome of the simulation to analyze the results that will determine factor influence (main effect), significant factor (ANOVA), optimum condition, estimate performance, etc. The study will analyze the lean

tool separately, the agile tool separately, and the combination of lean and agile tools separately then compare the results of their differences based on the amount of performance improvement range when a single tool is used compared to when the combination of both tools is used. The study will also compare the loss function in each and then compare it to verify if both tools save more resources than a single tool by reducing waste in the new product development design process. The ANOVA will also help to identify significant individual factors contribution which help to disclose the contribution of both lean and agile tools toward improving performance.

4.1 Taguchi Single Lean Data Collection & Analysis

The Taguchi lean data collection will be based on an array of L8 (2^7). The selected seven (7) factors in the context of the hospital temperature measuring instrument design process are procurement cost, assemble cost, information flow cost, manufacture cost, work in process, material flow cost, and testing cost. The two levels will consist of level 1 and level II. Level I is low, and level II is high. The experimental design process will use Taguchi orthogonal arrays. Moreover, the Taguchi orthogonal array was designed based on the combination of Latin squares first invented by Euler (Roy, 2001). The Latin square combinations appear in equal numbers and combination can be done in several ways. The study experiment requires 8 experiments which can be combined in a Latin square. For instance, having the factor A: A1A2, factor B: B1B2, and factor C: C1C2 can be combined in a latin square format such as: A1B1C1, A1B1C2, , A1B2C1 , A1B2C1, A1B2C2 , A2B1C1 , A2B1C2, A2B2C1 and A2B2C2 (Roy, 2001). The study used an already existing standard combination from the Taguchi orthogonal array for eight experiments (8) to conduct its experiment based on latin square substitution. The Taguchi orthogonal array requires 8 experimental trials, and seven factors (L8 (2^7)) for a single lean experiment. The value in the table is based on Latin square calculation substitution so there will be no confusion with the same value of 1 in level 1 & 2 representation below.

Table 4.0 Taguchi Orthogonal array combination using Latin square

factors	Level I	Level II
Procurement cost	1	1
Assemble cost	1	1
Information Flow cost	1	2
Manufacture cost	1	2
Work in process	2	1
Material. Flow cost	2	1
Testing cost	2	2

The above data was transferred into Qualitek-4 software by clicking on design to select an automatic design to proceed with the Taguchi simulation process for performance improvement. The simulation of a single lean data generated the main effect result, significant factor (ANOVA) result, optimum condition and performance result, and interactions, factor contributions result, variation reduction plot etc., The results from the simulation Qualitek-4 software results are represented in both table format and graphs below.

Table 4.1 Qualitek-4 Simulation Main effect result (Average effects of factors and Interaction)

for Lean

Expt. File: PISTON Q4W			Data type: S/N Ratio	
Level I (L1): Low; Level II (L2): High			QC type: Smaller is better	
No	Factors	Level I (L1)	Level II (L2)	Relative influence Factor (L2 - L1)
1	Procurement cost	1.332	70	68.66
2	Assemble cost	35.268	36.064	.795
3	Testing cost	35.268	36.064	.795
4	Information flow cost	34.075	37.257	3.181
5	Material flow cost	34.075	37.257	3.181
6	Work in process	33.01	38.322	5.312
7	Manufacture cost	33.01	38.322	5.312

The simulation result in the above table shows that using only a lean tool will have a major relative influencing factor of procurement cost which impacts the performance improvement process during production. The lean tool helps to eliminate the total cycle time and these lean activities are inevitable.

Simulated Main effect lean Graph

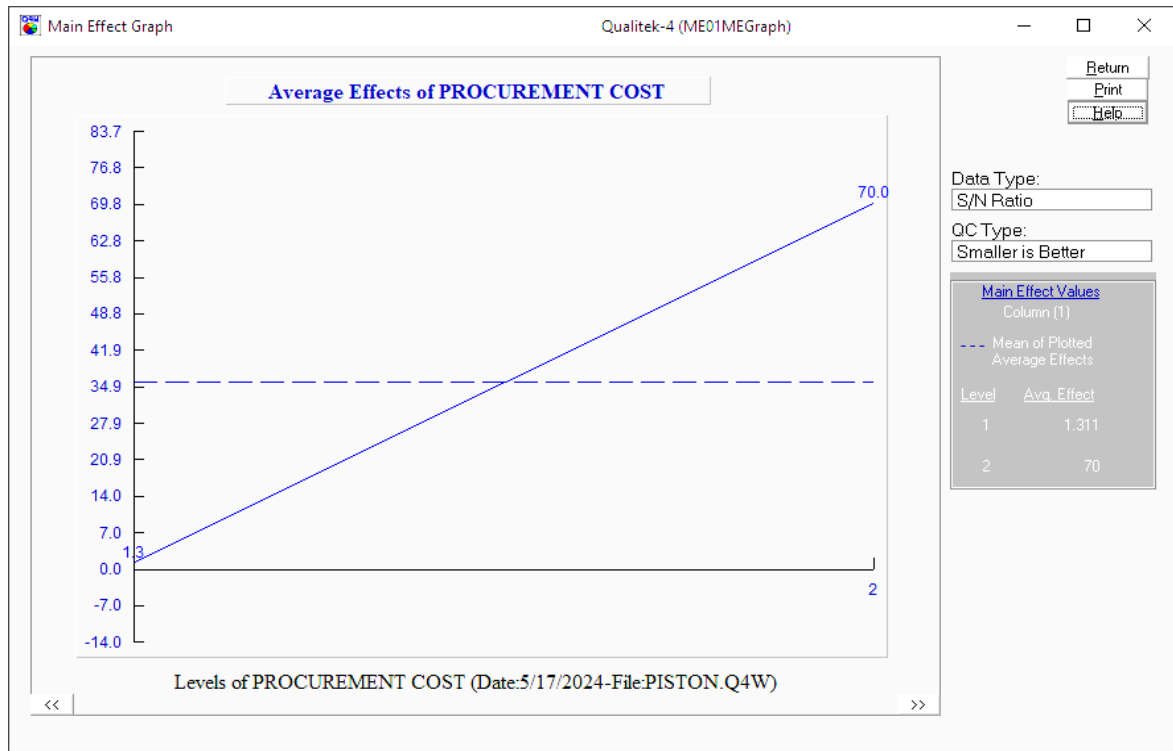


Fig 4.0 Qualitek-4 lean main effect results

The Qualitek-4 simulation main effect lean graph result shows that the main effect, which is procurement cost, started its initial relative maximum performance at 34.9 at y axis. The other factors combined with the main effect was able to improve the performance process to 70. This shows that other influencing factors in the process are likely to experience higher variation/waste. The performance of other factors reveals that the lean tool was not able to offer uniform distributive influence, and this inefficiency will result to higher total cycle time waste.

Simulated main effect multiple graphs for lean result

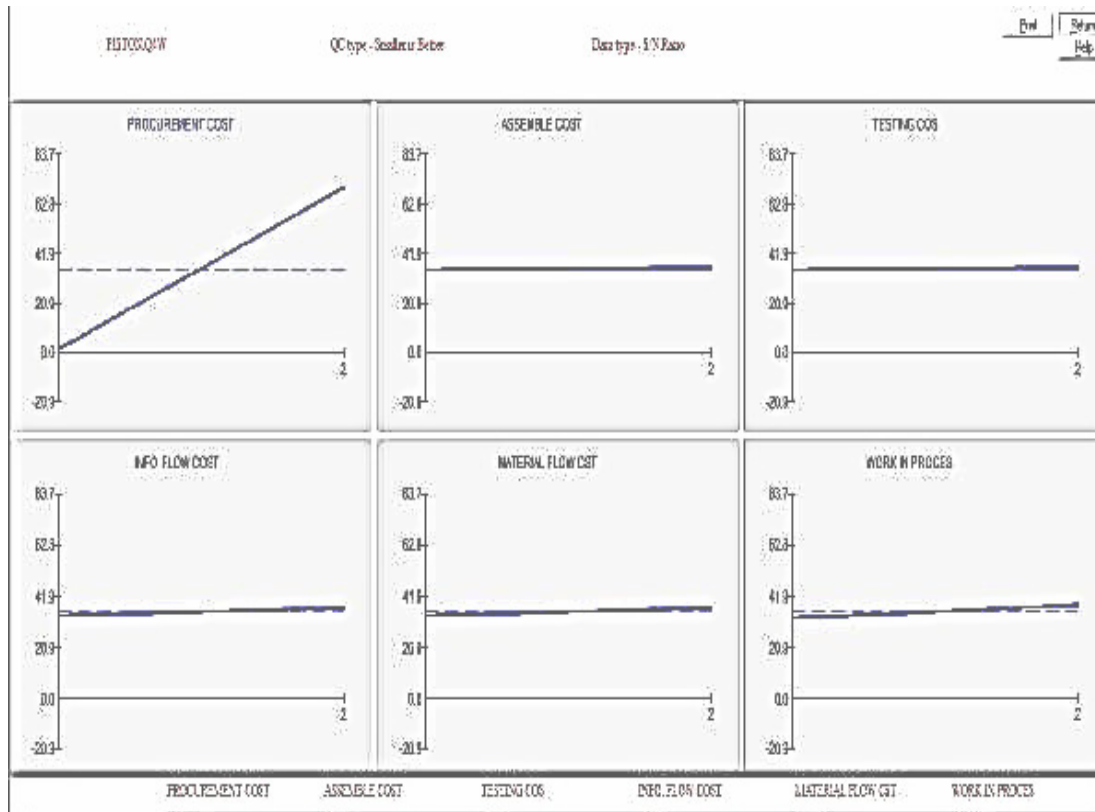


Fig 4.1 Qualitek-4 lean multiple graph Result

The Qualitek-4 simulation graph shows that the procurement cost has a significant interaction result while other factors do not have significant interaction graph. Therefore, the interaction between factors for the seven lean factors = $n(n-1)/2$ where n = number of factors can be calculated to further the graph analysis. The study generates that interaction between the seven lean factors = $7(7-1)/2 = 21$ interactions (Nasab & Zare, 2012; Roy 2001). The 21 number of interactions reveals that there is small amount of factor interaction distribution that will probably result to a poor performance improvement process because of high total cycle time.

Table 4.3 Simulated Qualitek -4 Optimum Conditions & Performance result.

Expt. File: PISTON Q4W		Data type: S/N Ratio		
QC type: Smaller is better				
No	Factors	Level description	Level	Contribution
1	Procurement cost	1	2	34.333
2	Assemble cost	1	2	.398
3	Testing cost	2	2	.398
4	Information flow cost	2	2	1.591
5	Material flow cost	1	2	1.591
6	Work in process	1	2	2.656
7	Manufacture cost	2	2	2.656

Total contribution from all factors **43.623**

Current Grand Average of performance **35.666**

Expected Result at Optimum Condition **79.289**

The simulated table of lean optimal performance result above shows that the current condition based on signal-to-noise ratio (S/N ratio) performance starts from 35.666 to a maximum performance improvement of 79.289. Therefore, the total size of improvement can be calculated by the difference of 79.289 minus 35.666. The use of single lean tool gives an improvement condition value of 43.623 based on the difference calculation above.

Relative influence of factors and interactions for Lean simulation

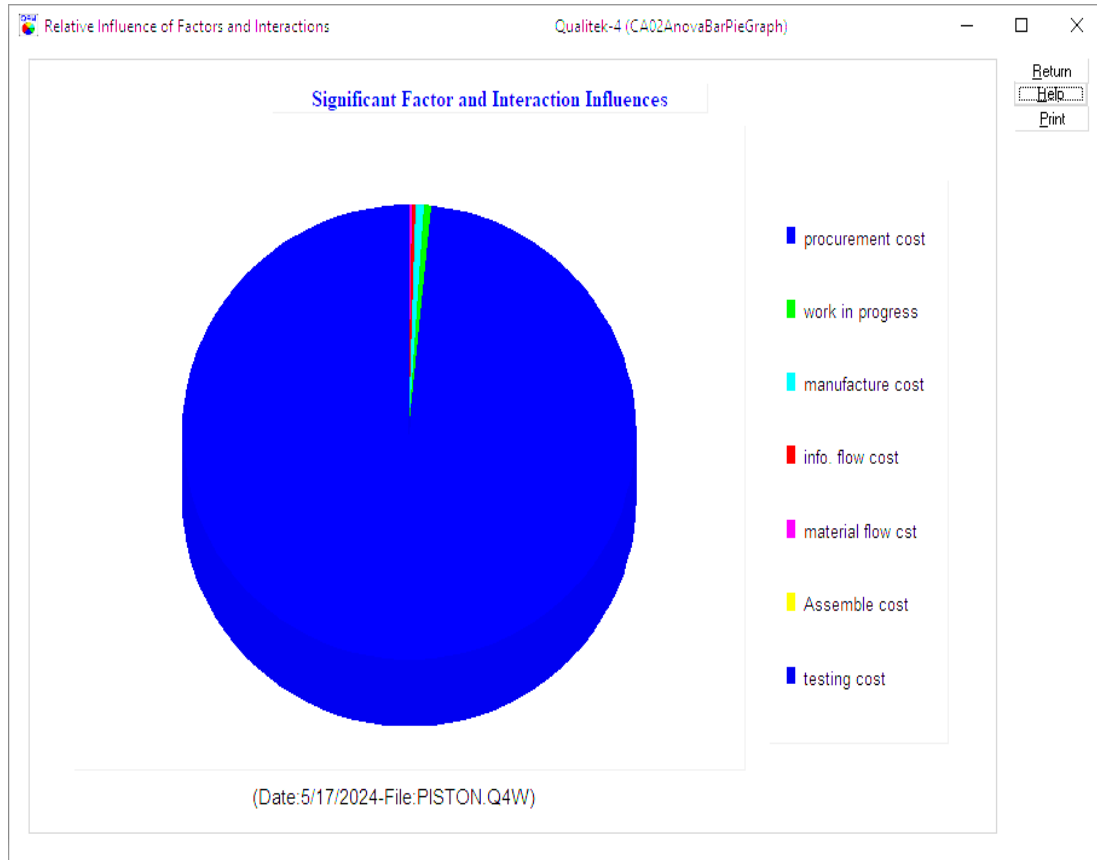


Fig 4.2 Qualitek-4 Pie chart result

The Qualitek-4 software pie chart result revealed that the procurement cost was the highest significant influencing factor. Therefore, it showed that poor interaction distribution exists which resulted in high total cycle time waste in the lean process. Therefore, a high total cycle time revealed that the use of lean tools alone will create a lot of waste, and this impacts the size of improved condition to 43.623.

Factor contributions for lean simulation.

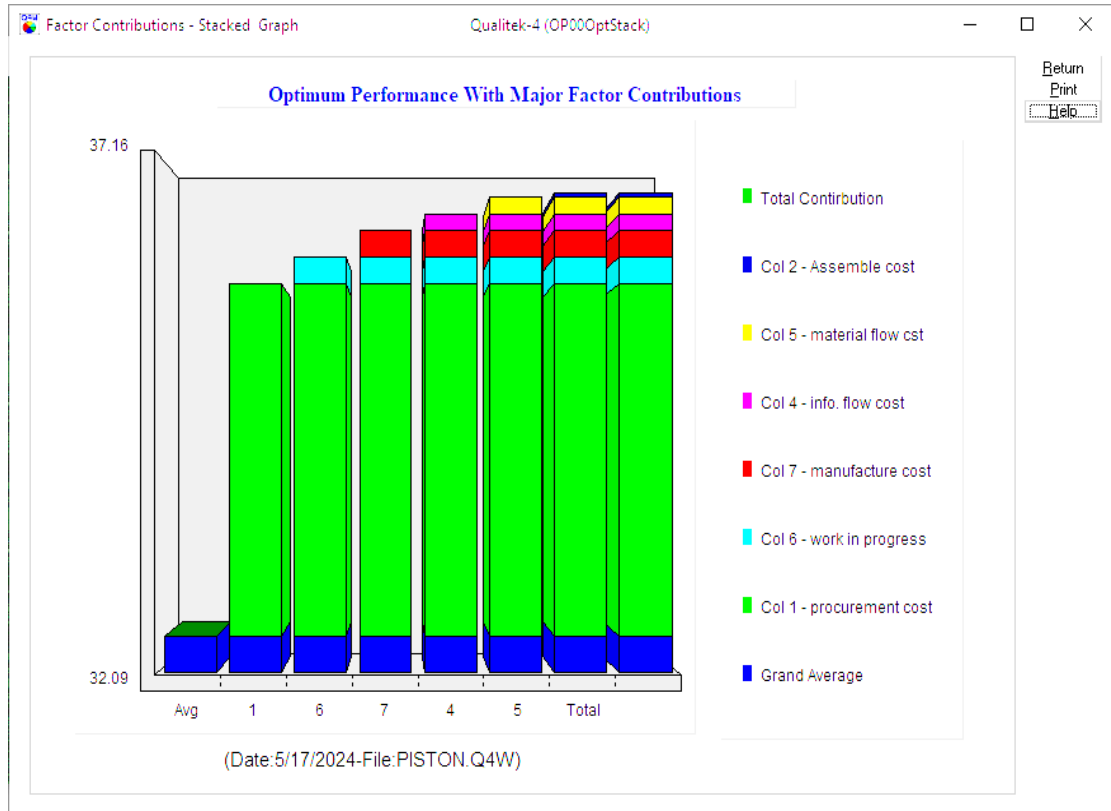


Fig 4.3 Qualitek-4 Bar chart result.

The Qualitek-4 software bar chart result reveals the contribution of each factor. Procurement costs have a significant influence during all-factor interaction. The bar chart reveals poor factor interaction distribution. This poor distribution reveals the inability of a single lean to remove all existing waste simultaneously. The color of the bars explain the contribution of each process during simulation.

Performance distributions plot for Lean Simulation

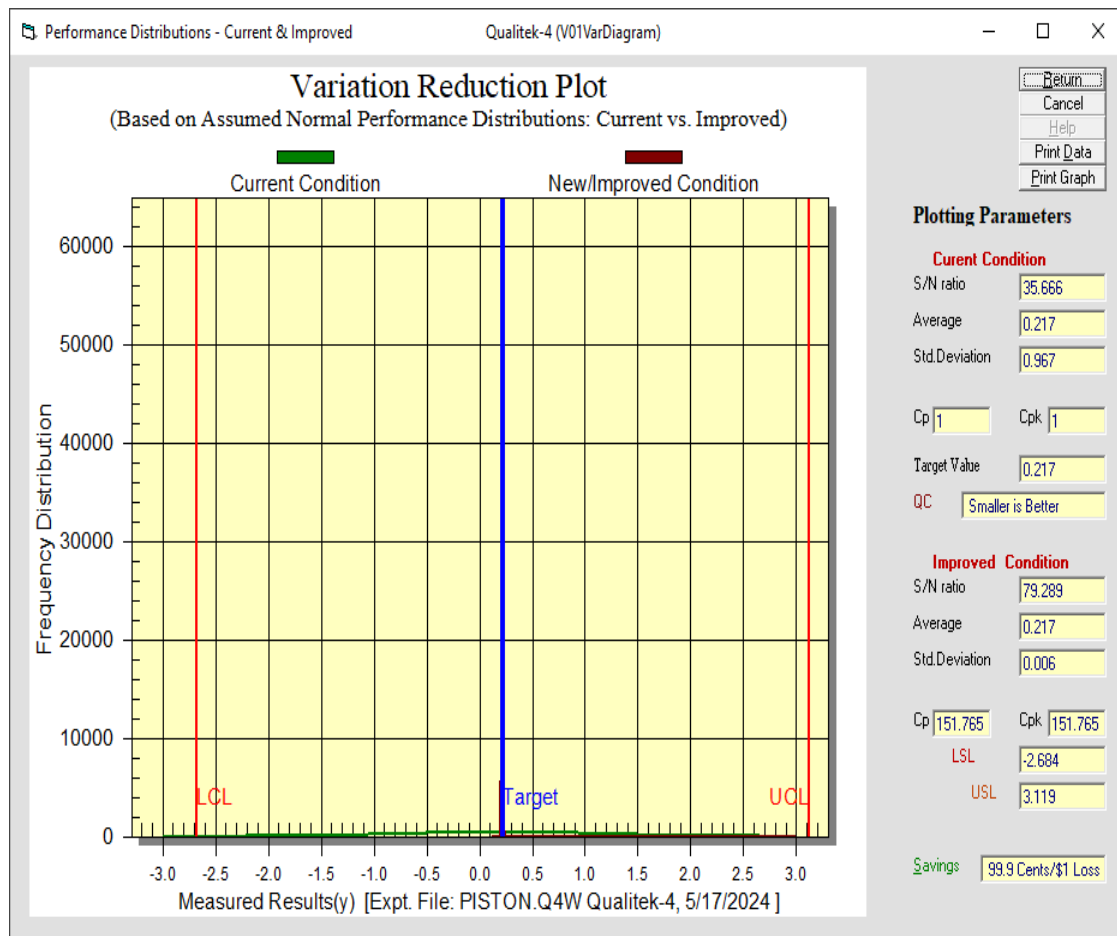


Fig 4.4 Qualitek-4 performance distribution result

The performance distribution table shows that there is no uniform distribution because of one significant influential factor (procurement cost) in the lean process. The distribution graph reveals that other factors are dormant. The effect of poor distribution causes the current condition to only improve from 35.666 to 79.289 which reveals that there is a likelihood that high total cycle time waste exists in using a single lean tool. The distribution graph shows a total improved values of 79.289 minus 35.666 which gives 43.623. The Cp and Cpk for a single lean was 151.765.

Lean plot for loss function for lean simulation

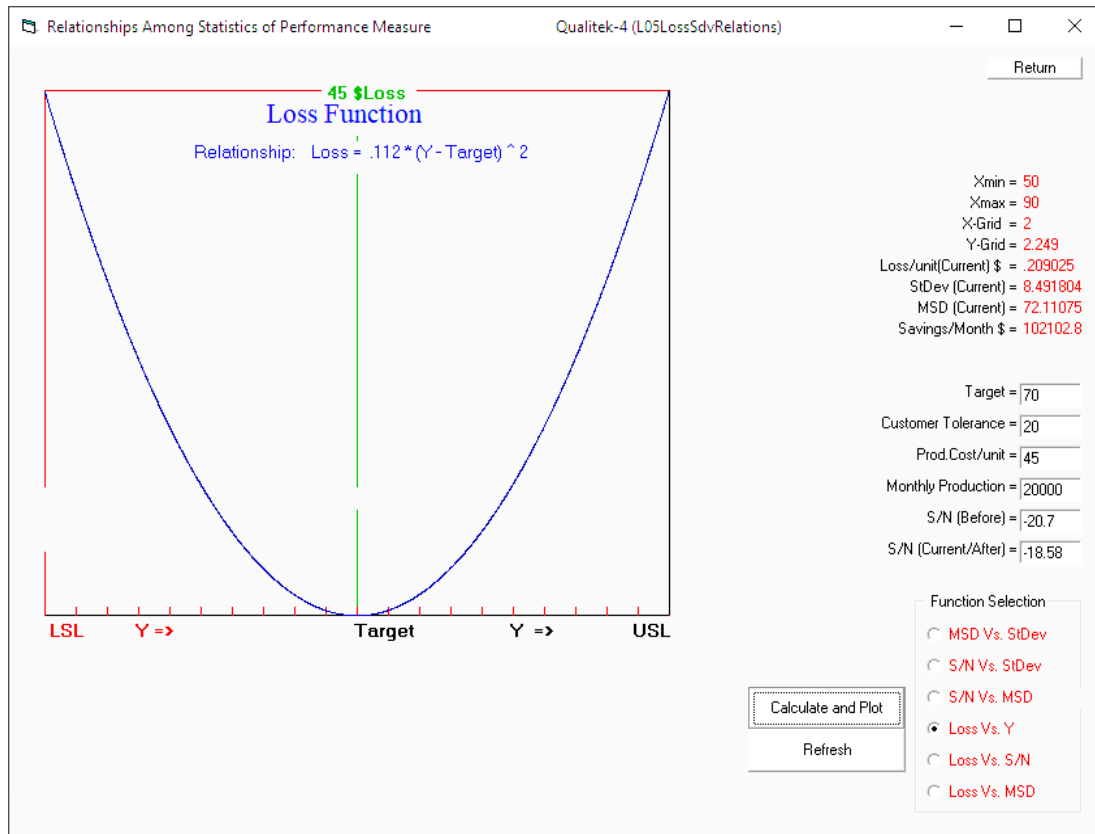


Fig 4.5 Qualitek-4 loss function result

The loss function is a parametric function used to make a product robust which results from customer complaints which is said to be a cost of rejection when parts are made out of specification. The Taguchi **loss** function helps to calculate financial losses resulting from total cycle time. Moreover, using the above relationship loss formula to calculate losses/savings. Relationship loss = $112 (Y - \text{Target})^2$ where $Y = \text{USL} - \text{LSL}$. Having that $\text{USL} = \text{upper specific Limit} = 79.289$ and $\text{LSL} = \text{Lower specific limit} = 35.666$. then $Y = (79.289 - 35.666) = 43.623$. Having the target as 70. Therefore, the study proceeds that Financial relationship loss = $112 (43.623 - 70)^2 = 112 \times (-26.377)^2 = 77,923.566$. The study based on this data concludes that using only lean will cause relationship loss of 77,923.566 value as a waste.

Process capability graph of Cp and Cpk for Lean Simulation

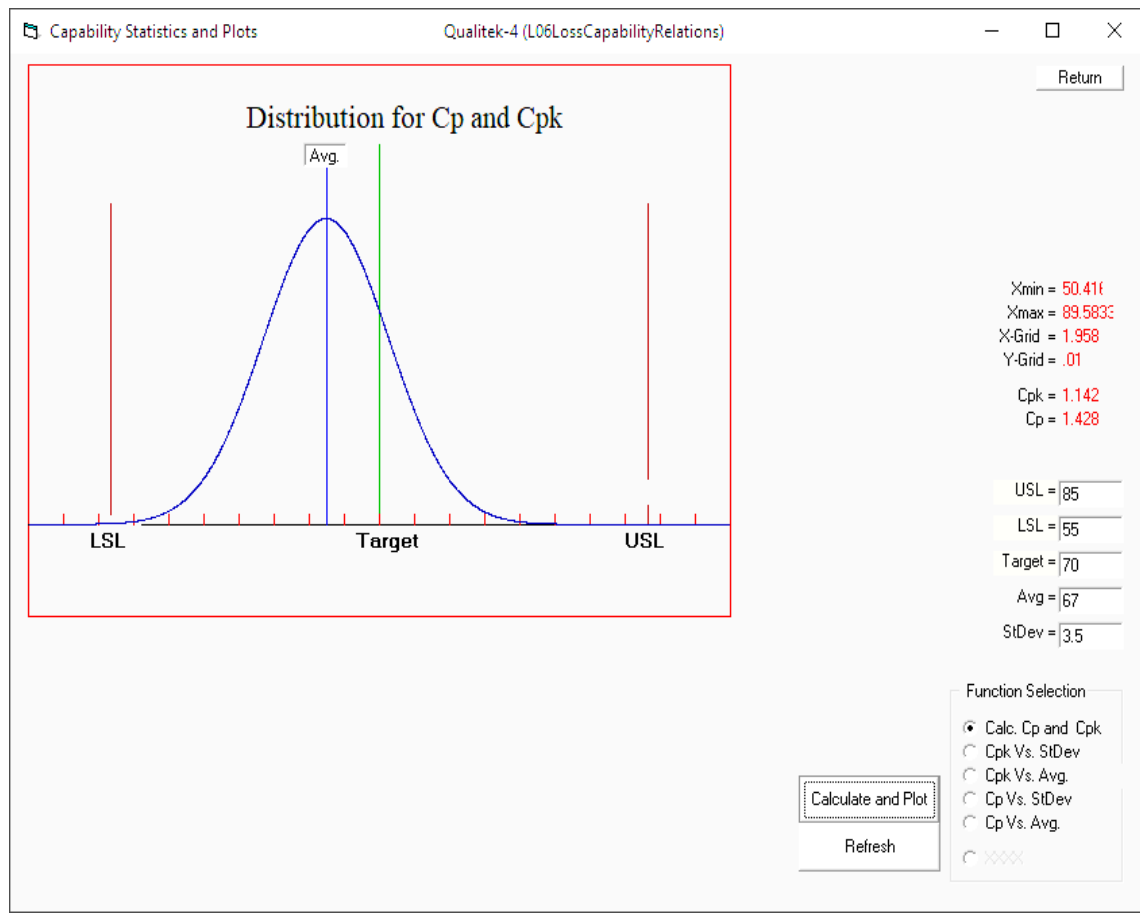


Fig 4.6 Qualitek-4 Cp and Cpk result

Cp is the process capability ratio and Cpk is the process performance ratio of the lean process. The cp value above reveals the fitness of a process into a specific lean process, and the Cpk above reveals the lean process performance ratio. The Cp and Cpk measure the process's ability to meet specification requirements. Cp measures how a system can perform during a lean process if all conditions remain constant, and Cpk helps to predict the behavior of a lean process to reflect the actual process mean. The lean process uses Cp and Cpk to boost the capability to analyze where improvement performance is required at any time in any process. The Cp and Cpk helps the manager to understand the performance limit requirement as customization increases at different market conditions, and this support the lean process towards achieving zero cycle time waste.

4.2 Taguchi Single Agile Data Collection & Analysis

The Taguchi agile data collection will be based on an array of L8 (2^4). The selected four (4) factors in the context of hospital temperature measuring instrument design process are procurement time, assembly time, information flow time & delivery time. The two levels will consist of level 1 and level II. Level I is low, and level II is high. Table 4.4 below is a Taguchi-designed standard based on the Latin square combination (Roy 2001). The value one in level 1 and one in level 2 is based on Latin square combination calculation so there will be no confusion on how one was obtained in level 1 & level 2.

Table 4.4 Taguchi Orthogonal design for agile based on the Latin square combination

factors	Level I	Level II
Procurement time	1	1
Assemble time	1	1
Information Flow time	1	2
Delivery time	1	2

Table 4.5 Qualitek – 4 simulated Main effect result (Average effects of factors and Interaction) for Agile

Expt. File: PISTON Q4W			Data type: S/N Ratio	
Level I (L1): Low; Level II (L2): High			QC type: Smaller is better	
No	Factors	Level I (L1)	Level II (L2)	Relative influence Factor (L2 - L1)

1	Procurement time	1.311	70	68.689
2	Assemble time	35.245	36.064	.817
3	Information flow time	34.053	37.257	3.204
4	Delivery time	32.988	38.322	5.334

The simulation result from the qualitek-4 simulation result in the above table reveals that using an agile tool will have a major relative influence factor of procurement time which impacts the amount of performance improvement process during production although other factors such as information flow time and delivery time also have significant contribution but not in comparison with procurement time.

Simulated Qualitek -4 Main effect Graph for Agile simulation

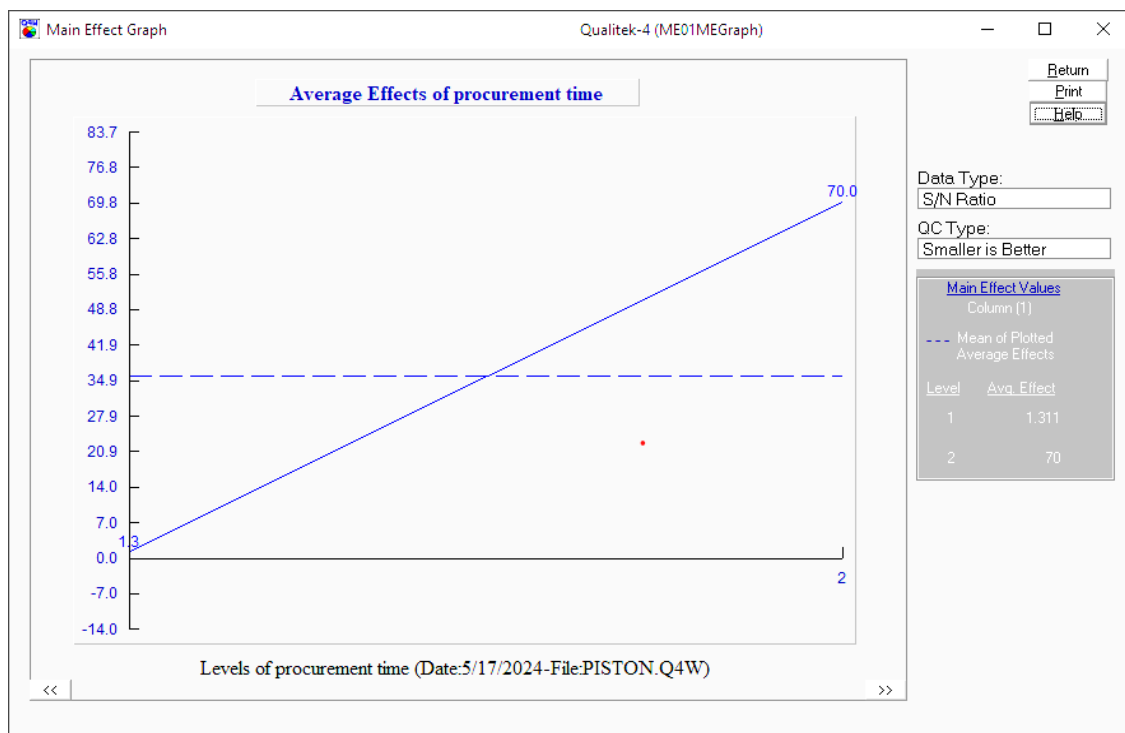


Fig 4.7 Qualitek-4 simulated agile graph result

The qualitek-4 simulation effect agile graph results show that the main effect, which is procurement time which started its relative maximum performance at 35.655 at y-axis. The other factors combined with procurement time improve the process to 70s. The low contribution in performance of other factors shows that the agile tool does not offer distributive influence in the entire process because higher variation/waste is likely to exist, and this results to inefficiency that result to significant lead time waste when using a single lean tool.

Qualitek-4 simulated Main effect multiple Graph for Agile simulation

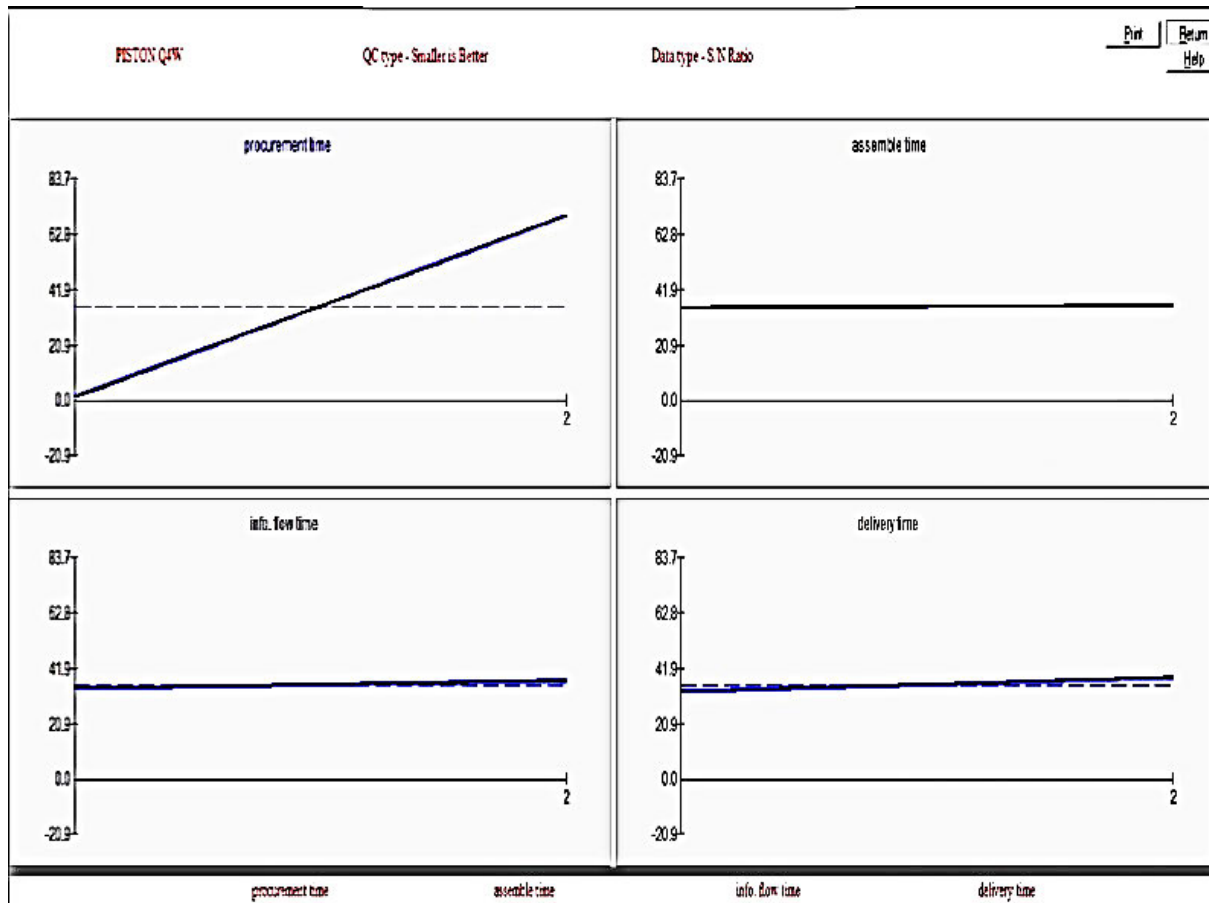


Fig 4.8 Qualitek-4 Agile multiple main effect graph result

The Qualitek-4 The Qualitek-4 simulation graph shows that the procurement time has a significant interaction graph result with other factors while other factors do not have significant interaction result. The interaction factor for the 4 factors = $n(n-1)/2$ where n = number of factors. Therefore, the total number of interactions that exist in the agile process = $4(4-1)/2 = 6$. The total number of interactions is very small, and this reveals that small amount of interaction distribution will result to poor performance improvement because of high total lead time.

distributed so there is a high probability that a significant lead time waste exists in the process because of the difference in mean significance.

Table 4.7 Qualitek-4 Optimum conditions and performance result for agile

Expt. File: PISTON Q4W			Data type: S/N Ratio	
QC type: Smaller is better				
No	Factors	Level description	Level	Contribution
1	Procurement time	1	2	34.344
2	Assemble time	1	2	.409
3	Information flow time	2	2	1.602
4	Delivery time	2	2	2.666

Total contribution from all factors **39.02**

Current Grand Average of performance **35.655**

Expected Result at Optimum Condition **74.676**

The Qualitek-4 simulated table above of agile optimal performance result shows that the current condition based on signal to noise ratio was improved from 35. 655 to a maximum performance improvement to 74.676. Therefore, the total size of improvement can be computed from the difference of 74.676 minus 35.655 which gives 39.021. The use of single agile tool shows that it gives an improvement increment of 39.021 which reveals that substantial waste/variation exists.

Simulated Qualitek-4 Relative influence factors and interactions for Agile simulation

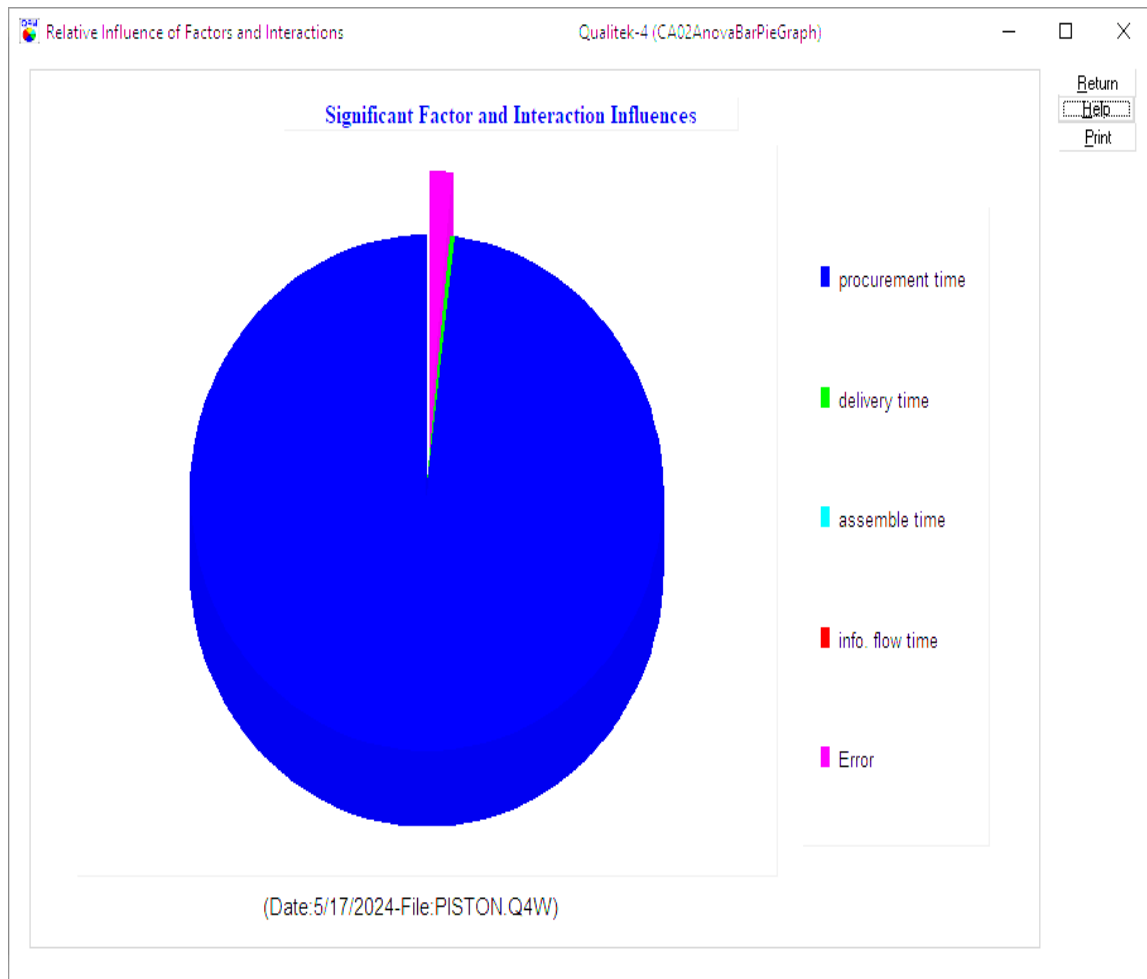


Fig 4.9 Qualitek-4 Pie chart result of relative influence factors

The Qualitek – 4 software pie chart result shows that the procurement time was the maximum significant influence factor with strong interaction, but other factors had a poor interaction with the least significant factor which reveals that there is the likelihood of poor distribution interaction that results in high lead time waste. Therefore, the result reveals that using only the agile tool method will be unable to manage all total lead time waste during the process.

Relative Influence of factors and Interactions for Agile simulation

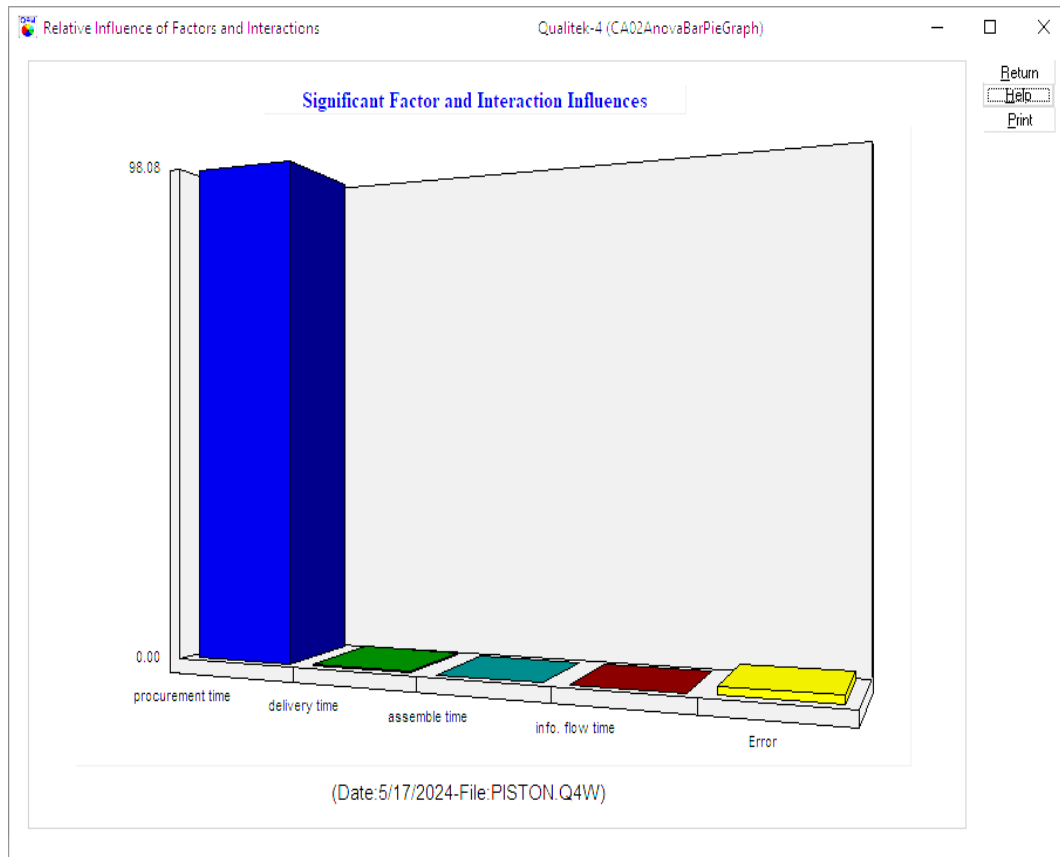


Fig 4.10 Qualitek-4 Bar chart result of relative influence factors

The Qualitek-4 software bar chart result shows the contribution of each factor. Moreover, the simulation shows that procurement time has a significant influence during all factor's interactions. The bar chart reveals poor factor interaction with other factors which shows that there is a substantial amount of waste during the process based on pie chart alignment.

Qualitek-4 simulated Performance distribution plot for Agile process result

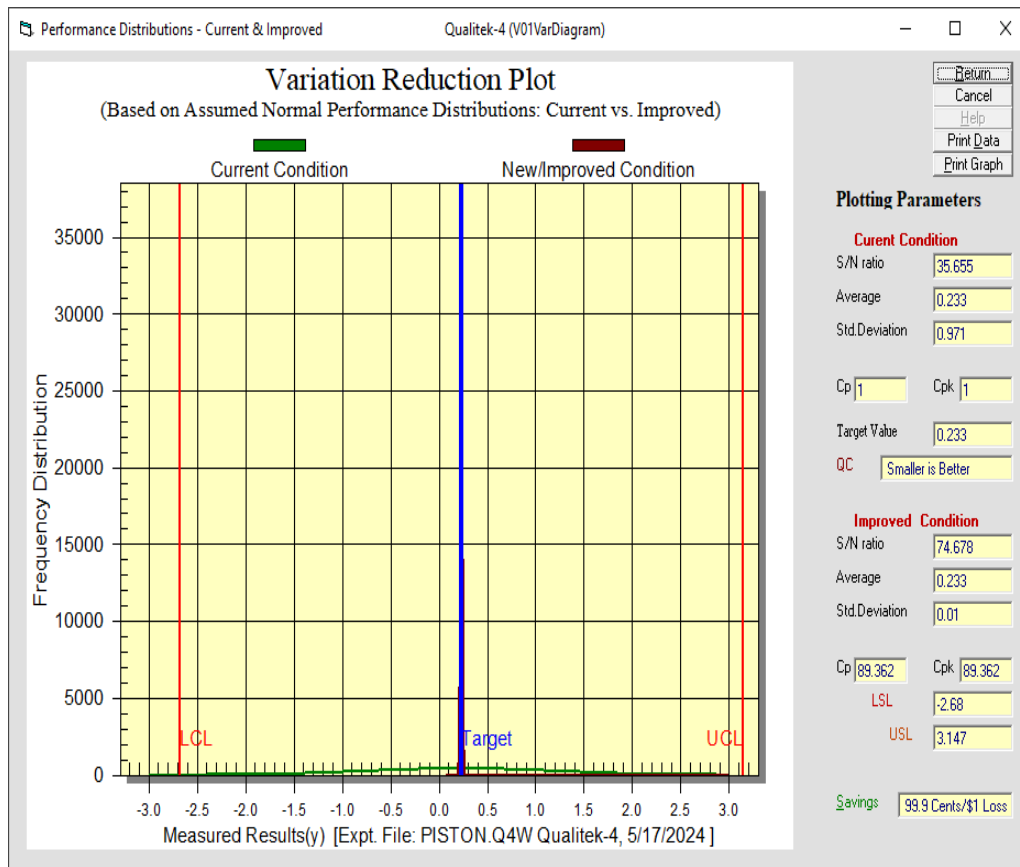


Fig 4.11 Qualitek-4 result for performance distribution plot for agile

The Qualitek – 4 software performance distribution plot shows that there is no uniform distribution because one factor (procurement time) has more than a 90% significant influence factor than other factors during the agile process, and this is the reason why the distribution exhibits a parallel between the current and the new improve condition. The effect of the poor distribution performance graph causes the current condition to only improve from 35.655 to 74.678, which shows that there is a high probability that there is a high total lead time waste that exists when using a single tool of agile. The Cp and Cpk for agile was 89.362

Qualitek – 4 simulated Agile plots for loss function graph for Agile simulation

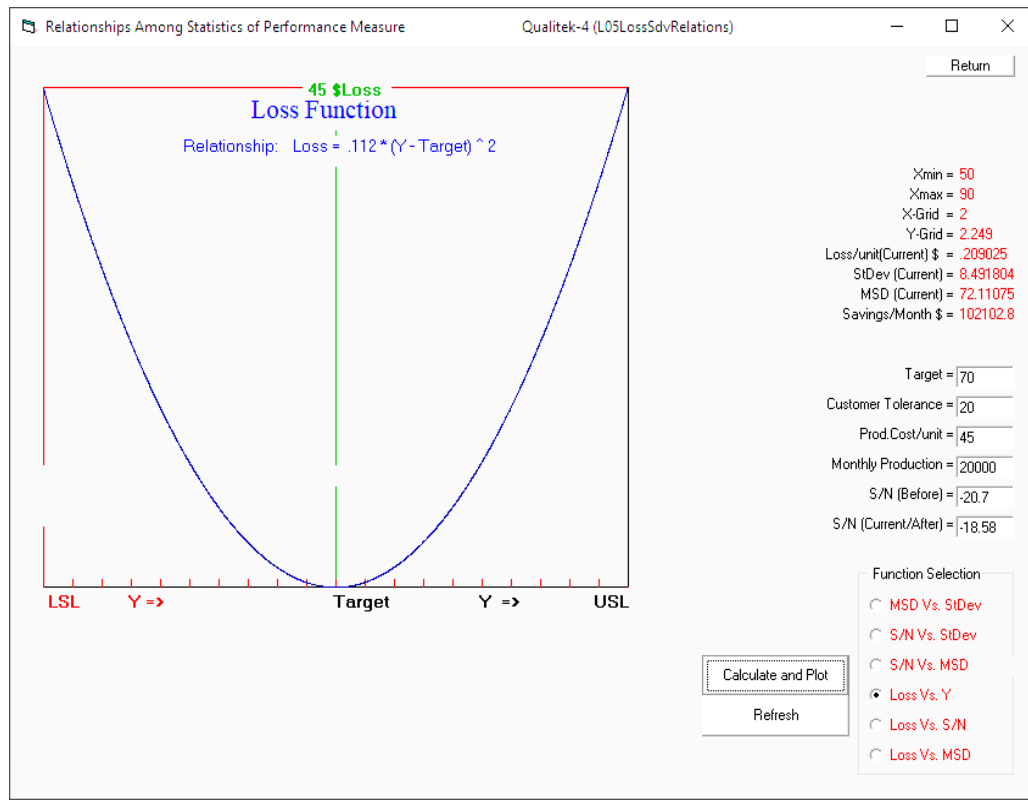


Fig 4.12 Qualitek-4 result for agile loss function

The Qualitek -4 loss function is parametric function of the Agile process used to make a product which results from complaint which is said to be the cost of rejection when parts are made of different specification. The Taguchi loss function helps to calculate financial losses resulting from total lead time waste. Moreover, using the above relationship loss formula to calculate losses/savings. Financial relationship loss = $112 (Y - Target)^2$ where $Y = USL - LSL$. Having that $USL = \text{upper specific Limit} = 74.676$ and $LSL = \text{Lower specific limit} = 35.655$. then $Y = (74.676 - 35.655) = 39.02$. Having the target above as 70. Therefore, the study proceeds that Relationship loss = $112 (39.02 - 70)^2 = 112 \times (-30.98)^2 = 107,493.165$. The study based on this data concludes that using only Agile will cause relationship loss of 107,493.165 value as waste.

Qualitek – 4 software Process capability graph of Cp and Cpk for Agile simulation

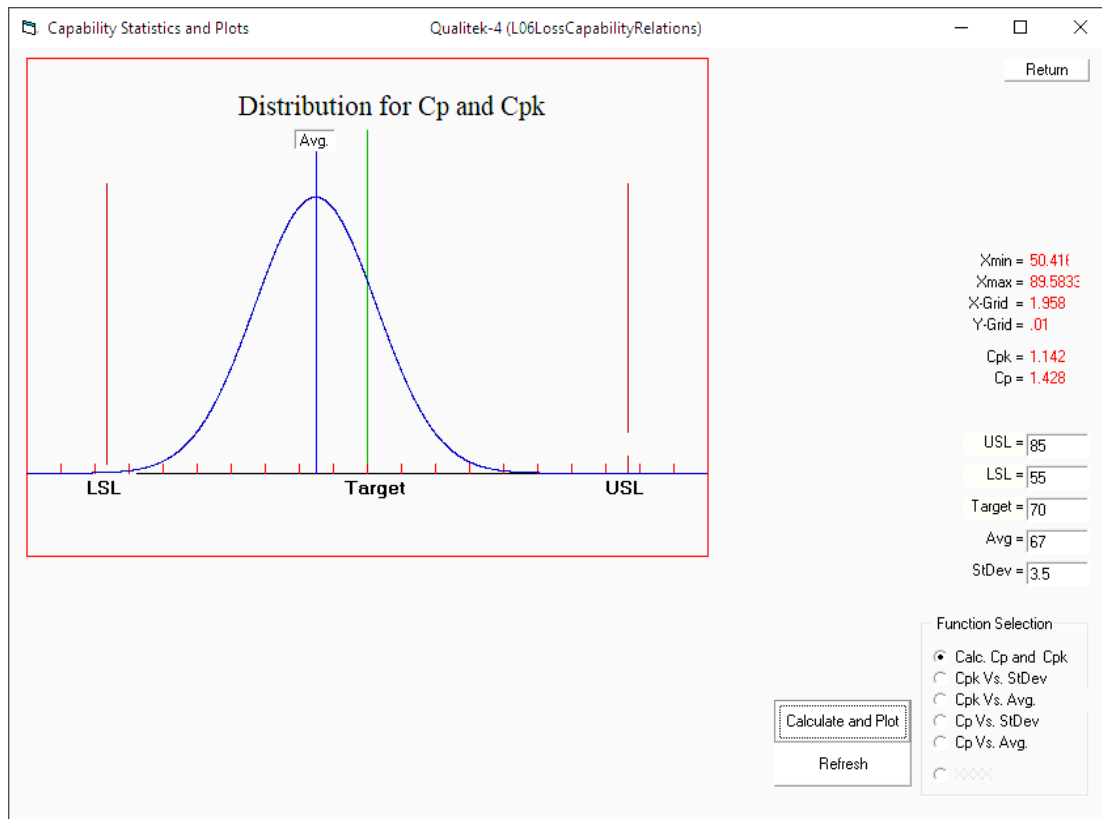


Fig 4.13 Qualitek-4 result of cp and cpk process capabilities

The CP is the process capability ratio of the Agile process, and the CP_k is the process performance ratio of the Agile process. The CP value above shows the fitness of a process into a specific agile process performance ratio. The data result CP and CP_k measure the process's ability to meet specification requirements. The CP data measures how an agile system can perform while in the process if all conditions remain constant, and CP_k data helps to predict the behavior of an agile process to reflect the actual process mean. The data result reflects that the agile process uses CP and CP_k to boast the capability to analyze where improvement performance is required at any time in any process. The Cp and Cpk helps the manager to understand the performance limit requirement as customization increases at different turbulence market conditions, and this support the agile process towards achieving zero lead time waste.

4.3 Taguchi Lean and Agile Integrated Data Collection & Analysis

The Taguchi lean and agile integrated data collection will be based on an array of L12 (2^{11}). The selected eleven (11) factors/activities based on lean and agile processes in the context of hospital temperature measuring instrument design process consist of both lean and agile factors. These factors/activities include procurement cost, procurement time, assemble cost, assemble time, information flow cost, information flow time, manufacture cost, work in process, material flow cost, testing cost & delivery time. The two levels will consist of level 1 and level II. Level I is low, and level II is high. Table 4.8 will be based on the Taguchi orthogonal design using the Latin square combination (Roy, 2001). The integrated factor of lean and agile represented in Table 4.8 will use the combination of both tools to remove the total cycle waste from the lean process and total lead times waste from agile waste.

Table 4.8 Taguchi orthogonal array design for combined lean and Agile factors (Latin square combination)

factors	Level I	Level II
Procurement cost	1	1
Procurement time	1	1
Assemble cost	1	1
Assemble time	1	2
Information flow cost	1	2
Information flow time	1	2
Manufacture cost	2	1
Work in process	2	1
Material flow cost	2	1
Testing cost	2	2
Delivery cost	2	2

Data collection procedure: The procedure uses simulation process involving the lean and agile factors using Taguchi simulation approach. The Taguchi approach consists of lean and agile activities/factors which consist of 11 factors (Procurement cost, Procurement time, Assemble cost, Assemble time, Information flow cost, Information flow time, Manufacturing cost, Work-in-process, material cost, testing cost, delivery time) . The lean and agile data simulation result expects to provide the main effect value of the lean and Agile, significant factor (ANOVA), optimum condition and performance, and interactions, factor contributions etc.

Table 4.9 Qualitek -4 Simulation Main effect result (Average effects of factors and Interaction) for lean & agile

Expt. File: PISTON Q4W			Data type: S/N Ratio	
Level I (L1): Low; Level II (L2): High			QC type: Smaller is better	
No	Factors	Level I (L1)	Level II (L2)	Relative influence Factor (L2 - L1)
1	Procurement cost	24.207	70	45.792
2	Procurement time	35.874	58.333	22.458
3	Assemble cost	35.164	59.043	23.878
4	Assemble time	46.831	47.376	.544
5	Information flow cost	46.831	47.376	.544
6	Information flow time	34.369	59.838	25.469
7	Manufacture cost	46.035	48.171	2.136
8	Work in progress	46.035	48.171	2.136
9	Material flow cost	45.325	48.881	3.555
10	Testing Cost	45.325	48.881	3.555
11	Delivery time	56.992	37.215	-19.777

The Qualitek -4 simulation result in the above table shows that using both lean and agile tools has several factors with significant relative influencing factor that offers a better improvement process than either single lean tool or single agile tool. The table also indicates that tangible amount of waste from total cycle waste resulting from lean process and total lead times resulted from agile process are significantly removed.

Qualitek - 4 Simulation Main effect graphs for combined lean and agile simulation

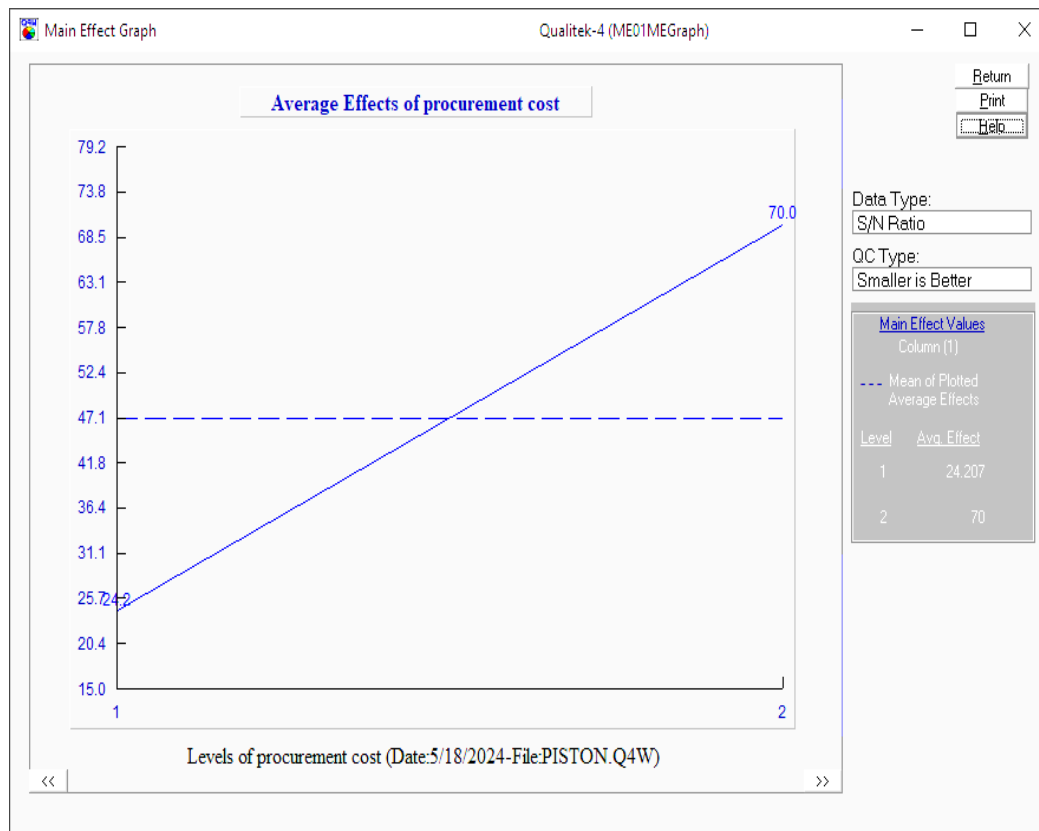


Fig 4.14 Qualitek-4 lean and agile main effect graph result

The Qualitek – 4 lean and agile simulation graphs showed that multiple factors from both lean and Agile have significant contributions to the main effect which helps to jump the initial relative performance to 47.1 at the y-axis which is higher than a single lean that starts at 34.9 or single agile that starts at 35.655. Moreover, the differences showed that a higher number of significant factors from both lean and agile tool contributions makes the process experience less variation/waste, and there is a significant substantial factors distributive influence in the process that will likely reduce total cycle time and total lead time waste.

Qualitek – 4 Simulation Main effect multiple graphs for combined lean and agile simulation

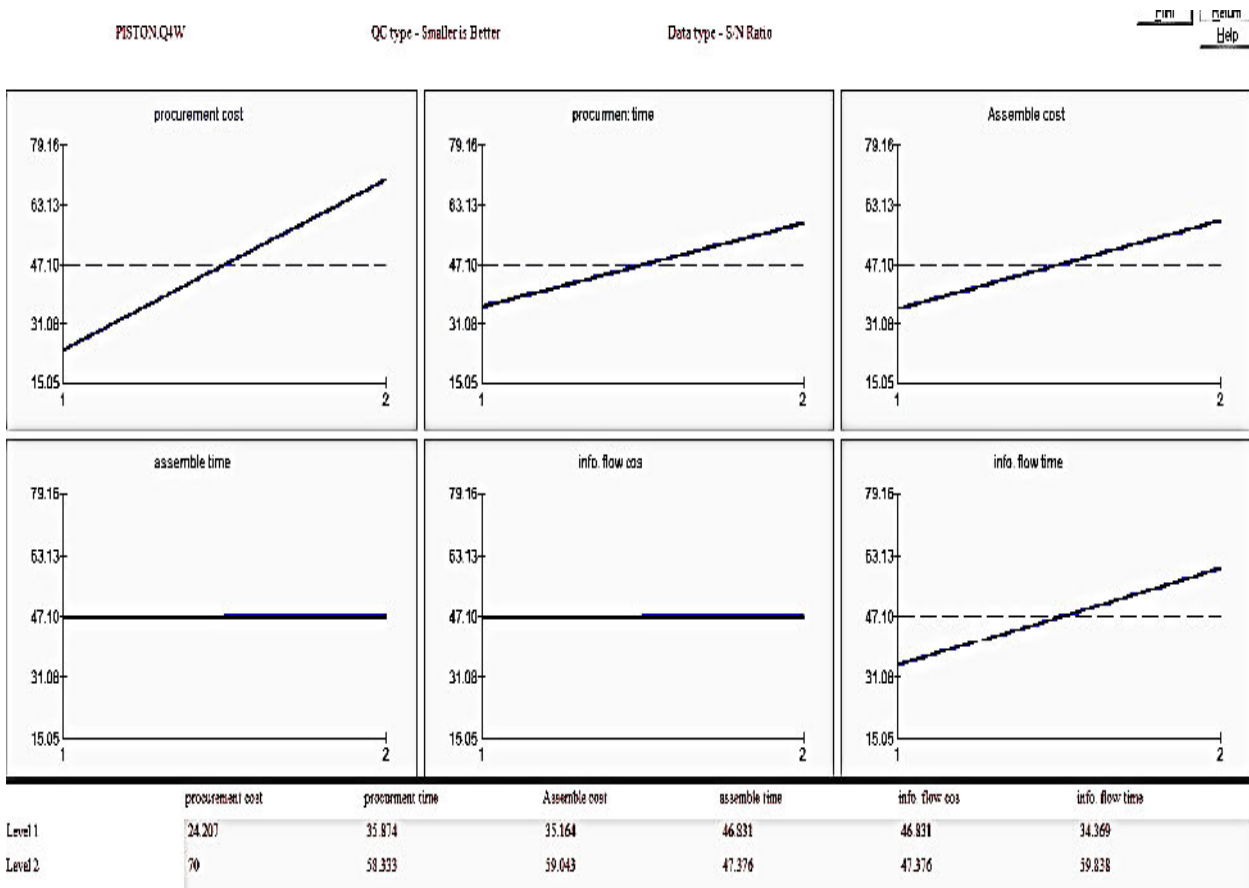


Fig 4.15 Qualitek-4 main effect multiple graphs for combined lean and agile result

The Qualitek – 4 simulation graph of the main effect multiple graphs simulation showed multiple factors from both lean and agile factors with significant interaction, unlike a single lean tool with only one significant interaction or single agile with one significant interaction. Therefore, multiple factor graph analysis showed that both lean and agile integration has a total of eleven factors (procurement cost, procurement time, assemble cost, assemble time, information flow cost, information flow time, manufacture cost, work-in-progress, material flow cost, testing cost, delivery time) which have an interaction = $n(n-1)/2$ where n = the number of factors (Nasab & Zare, 2012; Roy 2001). The interaction for lean and agile integration = $11(11-1)/2 = 55$. The total number of interactions when using integration of lean and agile tool is 55 which is higher than using single lean tool that is 21 or single agile tool that is 6. The higher interaction of 55 showed that a higher distribution influence has more probability to eliminate more waste than a single tool of lean or agile. This is the reason why the current improvement condition in simulated lean and agile starts with 47.1 at the y-axis with four significant multiple interaction graphs above. The use of a single lean tool has one significant interaction that starts at 34.9 at the y-axis which is less than four significant interactions of lean and agile that start at 47.1 at the y-axis. The study concludes that

poor distributive interaction in using a single lean tool is among the leading causes of high total cycle time waste that causes inefficiency and ineffectiveness in the production process. Moreover, the same condition applies to using a single tool of Agile that has only one significant interaction that starts at 35.655, and it is less when compared with lean and agile integration which has four significant multiple interactions that start at 47.1 at the y-axis. The poor limited distribution interaction of using a single agile tool of either lean or agile tool is the leading cause of total lead time waste that leads to inefficiency and ineffectiveness in the production process.

Table 4.10 Qualitek – 4 Significant factor (ANOVA) result for combined lean and Agile simulation

Expt. File: PISTON Q4W				Data type: S/N Ratio			
QC type: Smaller is better							
No	Factors	DOF (F)	Sum of Sqrs. (S)	Variance (V)	F- Ratio (F)	Pure Sum (s)	Percent age P (%)
1	Procurement cost	1	6290.823	6290.823	-	6290.823	49.381
2	Procurement time	1	1513.223	1513.223	-	1513.223	11.878
3	Assemble cost	1	1710.612	1710.612	-	1710.612	12.427
4	Assemble time	1	.892	.892	-	.892	.007

5	Informa tion flow cost	1	.892	.892	-	.892	.007
6	Informa tion flow time	1	1946.06	1946.06	-	1946.06	15.276
7	Manufac ture cost	1	13.688	13.688	-	13.688	107
8	Work in process	1	13.688	13.688	-	13.688	.107
9	Material flow cost	1	37.932	37.932	-	37.932	.297
10	Testing cost	1	37.932	37.932	-	37.932	.297
11	Delivery time	1	1173.442	1173.442	-	1173.442	9.211
Total		11	12739.188				100%

The ANOVA result shows multiple significant factors from both lean and agile tools, which showed that a strong interaction level exists when compared to a single lean or single agile with a limited interaction based on the 95% confidence interval. The ANOVA has a more significant mean interaction with multiple higher distributive interaction influences than single lean or agile. The higher distributive interaction showed that integration of lean and agile eliminates more waste and

has better effective efficiency than only a single tool of either lean or agile during the production process. The ANOVA result of lean and agile integration shows that factors contribute significantly to removing waste from total cycle time and total lead time than a single tool of lean or Agile with a limited factor significance.

Table 4.11 Qualitek – 4 simulated Optimum conditions and performance for combine lean & agile simulation

Expt. File: PISTON Q4W		Data type: S/N Ratio		
QC type: Smaller is better				
No	Factors	Level description	Level	Contribution
1	Procurement cost	1	2	22.896
2	Procurement time	1	2	11.229
3	Assemble Cost	2	2	11.939
4	Assemble time	2	2	.272
5	Information flow cost	2	2	.272
6	Information flow time	2	2	12.734
7	Manufacture cost	1	2	1.068
8	Work in process	1	2	1.068
9	Material flow cost	1	2	1.777
10	Testing cost	2	2	1.777
11	Delivery time	2	1	9.888

Total contribution from all factors

74.92

Current Grand Average of performance

47.103

Expected Result at Optimum Condition

122.023

The Qualitek- 4 optimum condition and performance simulated result of lean and agile tool integrated showed that the optimal performance result based on signal-to-noise increase from the current condition of 47.103 to a maximum performance improvement of 122.023, which was higher than using a single lean tool or single agile tool. Comparatively, using both lean and agile tools provides a performance improvement of 122.023 minus 47.103, which gave a value of 74.92. The performance value of integrated lean and agile tools is higher than a single lean tool with a performance improvement value of 79.289 minus 35.666, which gave a value of 43.623. Also, the performance value of the integrated lean and agile tool is higher than a single agile tool that has a performance value of 74.676 minus 35.655, which gave the value of 39.02. The study can confidently uphold from data results that using both lean and agile tools as a single tool offers better performance than a single lean tool or single agile tool. Moreover, the study can also uphold that the use of the lean and agile tools as one single tool eliminates both total cycle time waste from the lean process and total lead time waste from the agile process, which makes the tool offer more effective efficiency than either single tool of lean or single tool of agile tool.

Simulated Qualitek – 4 pie chart result of relative influence of factors and interaction for combined lean & agile

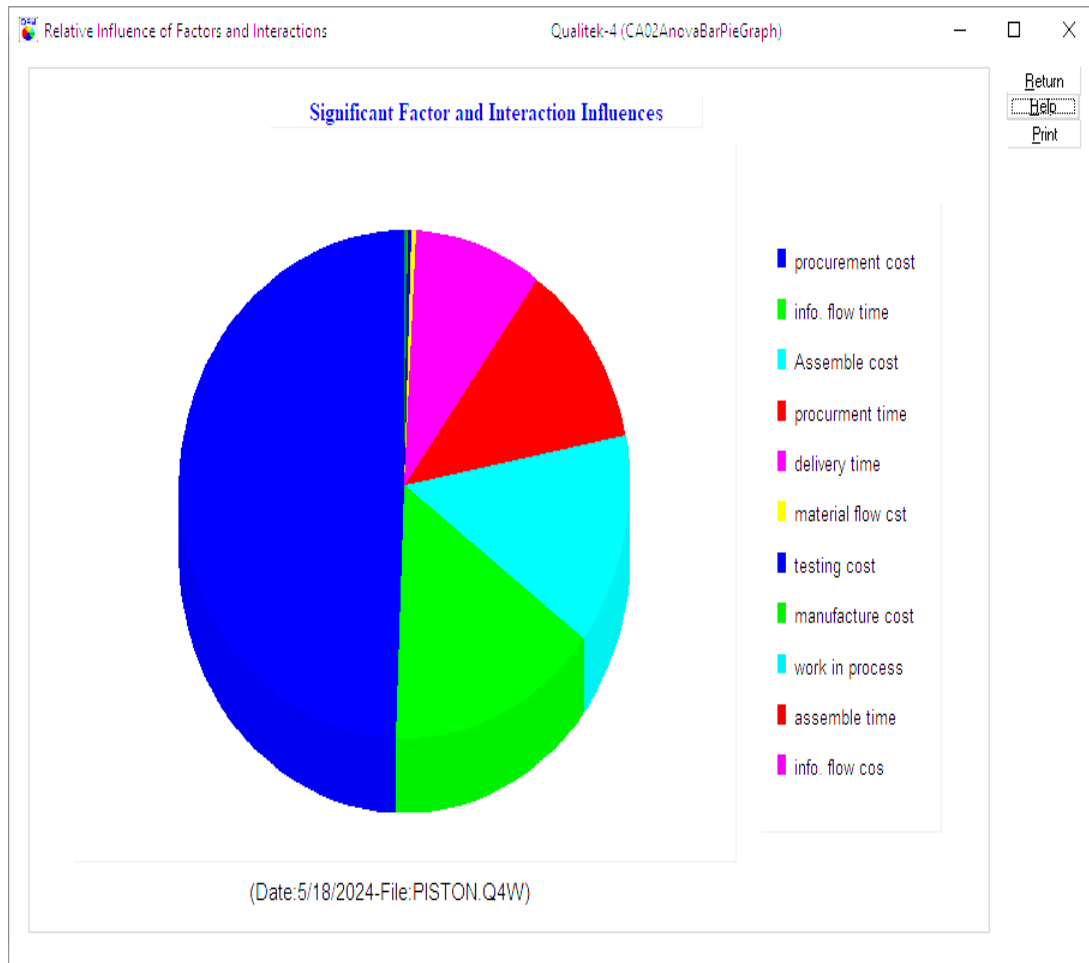


Fig 4.16 Qualitek-4 software pie chart interaction for combined lean & agile result

The Qualitek-4 software pie chart result shows multiple factors of both lean and agile have significant influence when compared with single tool of lean or single agile tool. The simulated pie chart result showed that both lean and agile tools are much more effective and efficient during removal of waste process from total cycle time waste and total lead times in the production process. The pie chart showed that majority of the factors are significant during the process which is better evidence of higher distributive interaction influence than using a single lean tool or single agile tool that have only one factor as a measure contributor which leads to higher inefficiency in the production process.

Qualitek -4 bar chart simulation of Relative influence of factors and interaction for combined lean and Agile result

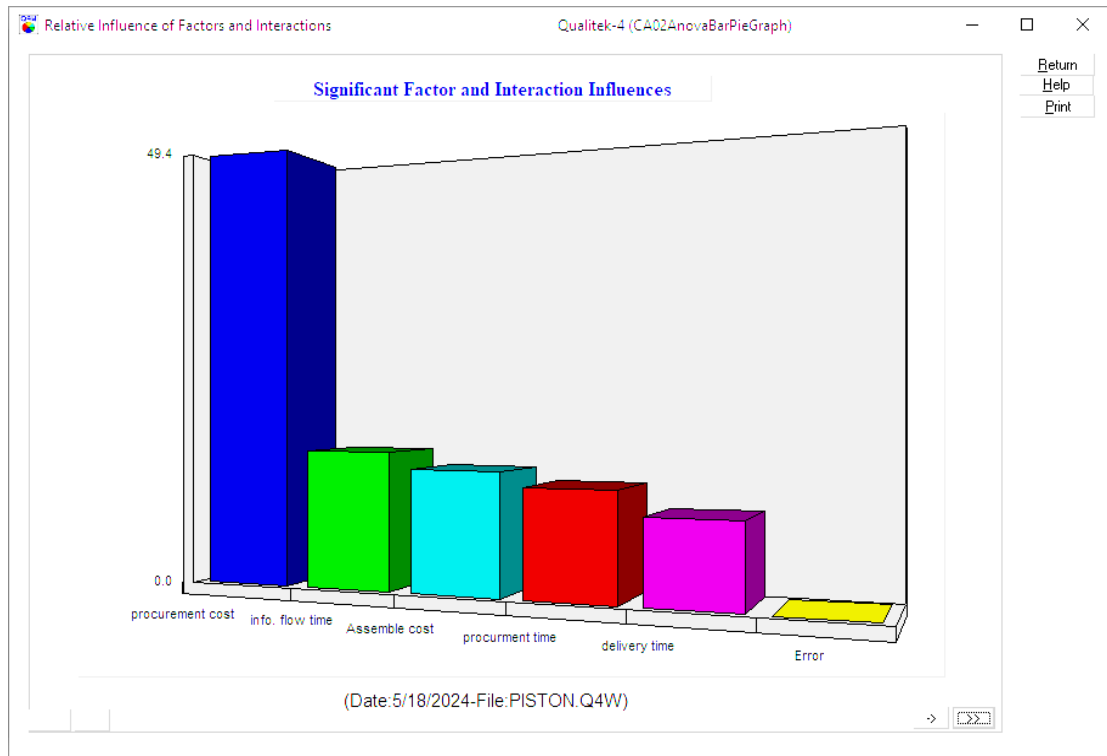


Fig 4.17 Qualitek-4 Bar chart result for combined lean and Agile

The bar chart revealed that the process distribution was quite different from either single lean or single agile. The chart revealed that more factors contributed to the process. The study also revealed that more waste was eliminated as many factors contributed simultaneously. The graph shows that both lean and agile tools were effective contributing factors during the process.

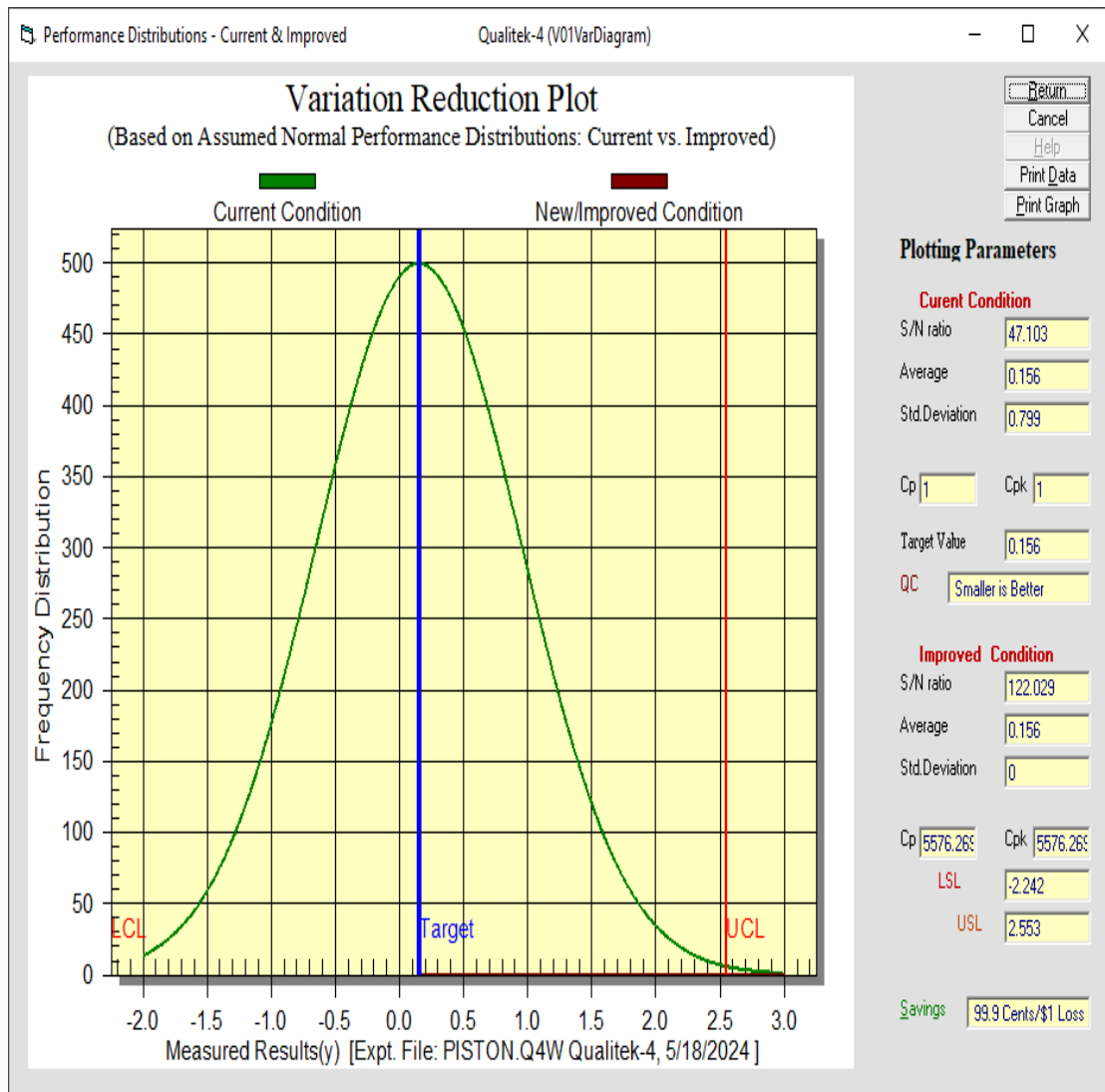


Fig 4.18 Qualitek-4 software result Performance Distribution Plot for combined lean and agile

The Qualitek-4 simulation performance Table in lean and agile shows a curve bell shape, which signifies the presence of interaction distributive influence from multiple significant factors from both lean and agile tools used in the process. The effect of the curve bell shape signifies that there is a likelihood that almost all the total cycle time waste and total lead time waste was eliminated because of multiple significant factor contributions from lean and agile tools that were very efficient and effective in generating a bell shape. The study also upholds that using only a single lean tool or a single agile tool can only offer a vertical shape and not a bell-shaped curve, which signifies that there is a huge presence of waste not eliminated in using only a single tool during the process. The current lean and agile from the bell shape curve shows that current condition performance improvement rose from 47.10 to 122.023, which gave a difference of 74.92 because of the significant contribution of both lean and agile tools. The performance value of integrated lean and agile tool based on the bell shape curve resulting from a high number of interactions and high distributive

interaction influence was higher than a single lean tool that has a performance improvement value of 79.289 minus 35.666, which gave a value of 43.623. The lower value of the single tool is one of the reasons why it is a vertical line because it lacks a higher number of interactions and uniform distributive interaction influence. Also, the performance value of the integrated lean and agile tool is higher based on the bell shape curve resulting from a high number of interactions and higher distributive interaction influence than a single agile tool that has a performance value of 74.676 minus 35.655, which gave the value of 39.02. The study concludes that a bell shape is the ideal production management strategy that eliminates both total cycle time waste and total lead time waste. The study upholds that the integration of lean and agile helps to support effective efficiency and effectiveness. The Cp and Cpk for lean and agile combined was 5576.269.

Qualitek – 4 Loss function for combined lean and agile simulation result

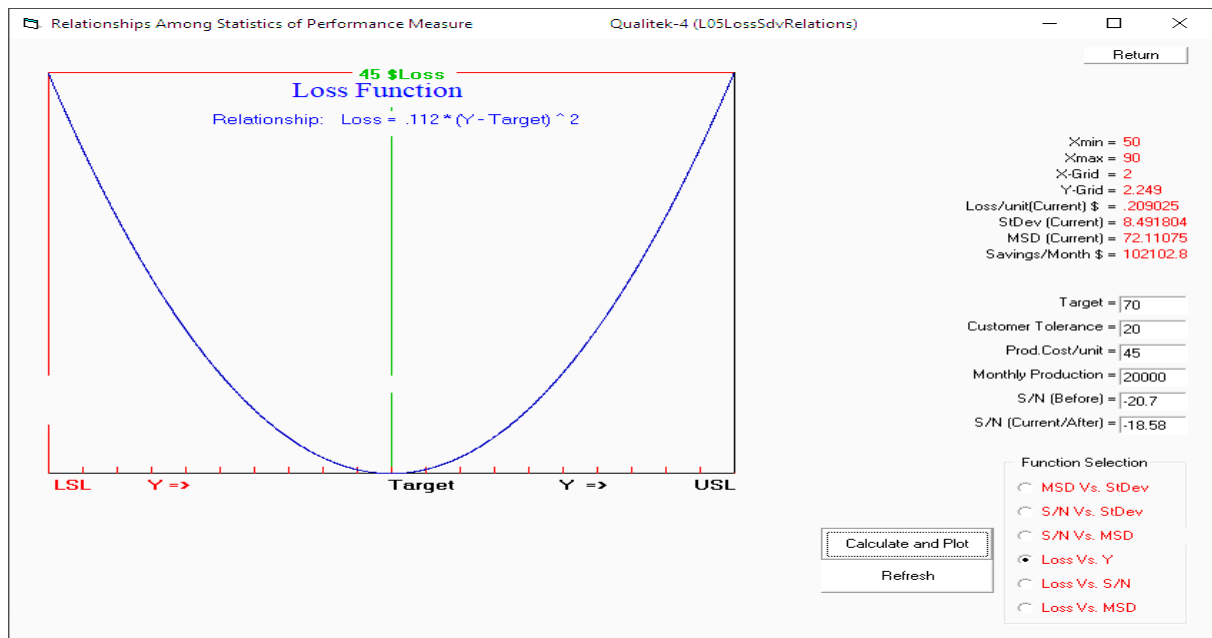


Fig 4.19 Qualitek-4 Loss function for combined lean and agile simulation result

The loss function is a parametric function used to make a product which results from customer complaints which is said to be cost of rejection when parts are made different from specification. Moreover, Loss can still be experience when it is made in a specific limits but loss can entirely be avoided if product are manufactured on target. Taguchi software observe relevant simulation assumption that depends on Taguchi orthogonal arrays used and choice of the factor input level selected. The Targuchi software will generate the standard target for the process automatically. The limitation of the study is that the author is limited to changing the values of the target during simulation but can set different specification limits using the formular recommended by the software

after the initial simulation output. The Taguchi loss function helps to calculate the financial losses resulting from the total cycle time and lead time. at different specific limits Moreover, using the above relationship loss formular to calculate losses/savings. Relationship loss = $112 (Y - \text{Target})^2$ where $Y = \text{USL} - \text{LSL}$. Having that $\text{USL} = \text{upper specific Limit} = 122.023$ and $\text{LSL} = \text{Lower specific limit} = 47.10$. then $Y = (122.023 - 47.10) = 74.676$. Having the target above as 70. Therefore, the study proceeds that relationship loss = $112 (74.676 - 70)^2 = 112 \times (4.676)^2 = 2448.877$. Moreover, the financial relationship loss of 2448.877 is the estimate of cost of quality at the performance level (Roy, 2001). The financial loss of 2448.877 is a waste converted to any monetary estimate such as US dollars or others. The financial relationship value estimate of 2448.87 can be influenced by the country factors of production cost (Nadir et al., 2025; Nugrahapsari et al., 2024). Roy 2001 highlighted that loss can still come within performance limits because it is still possible to have a loss even if parts are made within specific limits. Also, Roy 2001 added that losses are only absent when a part is made exactly on target. The study based on this data concluded that using lean and agile as a single tool will cause financial relationship loss of 2448.877 value as waste. Comparatively, the study concludes that using integration of lean and agile as a single tool will have a smallest amount of loss of 2448.877 amount of waste while using a single tool of lean alone will cause a waste of 77, 923.566 amount of waste. Also, using agile tools alone will cause 107, 493.165 amount of waste. The research study concludes that the integration of lean and agile as a single tool in a production process helps to eliminate waste drastically and saves more resources for a firm.

Qualitek -4 Process capability graph of Cp and Cpk

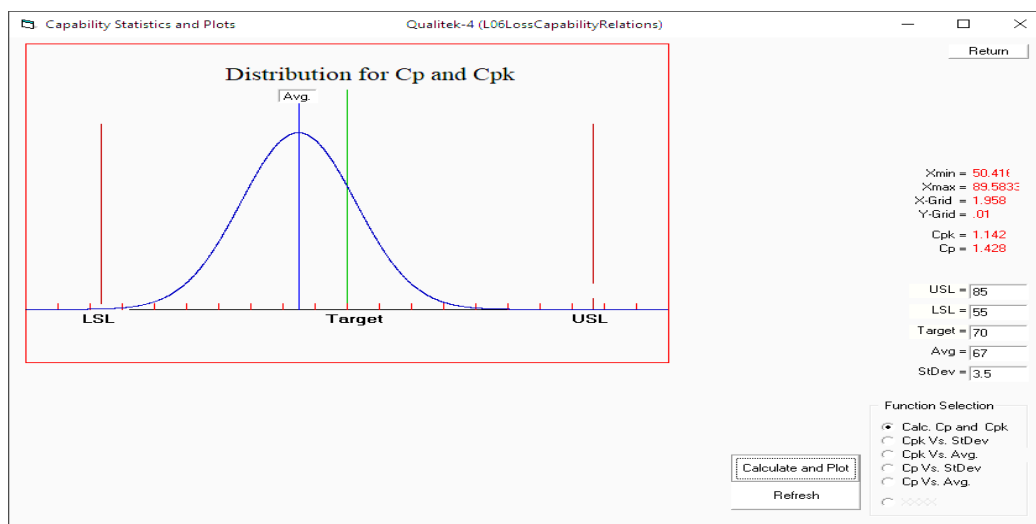


Fig 4.20 Qualitek-4 software Process capability graph of Cp and Cpk for lean and Agile

The C_p is the process capability ratio and CP_k is the process performance ratio of the lean process. CP value above reveals the fitness of a process into a specific process performance ratio. The cp and cpk measures the process's ability to meet specification requirements. CP measures how the lean and agile system will perform during the production process if all conditions remain constant, and CP_k helps to predict the behavior of a lean and agile process to reflect the actual process mean. The lean and agile process uses cp and cpk to boost the capability to analyze where improvement performance is required at any time in any process than either single tool of lean or agile. The practical significance of C_p and C_{pk} is that it informs a production manager on how to select lean and agile integration based on target to obtain higher cp and cpk that will remove more cycle waste and lead time. The C_p and C_{pk} will also help the production manager to estimate and minimize economic waste coming from cost of quality at any performance level (Roy, 2001). The output result of C_p and C_{pk} for lean and agile integrated together as one is 5576.269, the C_p and C_{pk} for a single lean is 151.765, and the C_p and C_{pk} for agile is 89.362. These results clearly revealed that lean and agile integration will remove more total cycle waste and total lead time waste than using either a single lean or single agile.

4.4 Process Comparison Performance Analysis

The Taguchi single lean simulation data result reveals that performance improvement increased from 35.666 to 79.289, which gives a total performance increment of 43.623. Also, the lean has a total of 21 interactions among its seven factors with poor distributive influence. The use of lean tools alone during the production process caused a loss of 77, 923.566 value. Also, The Taguchi single agile simulation data result reveals that performance improvement increased from 35.555 to 74.676 which, gave a total performance increment of 39.02. Moreover, agile has a total of 6 interactions among its four factors with poor distributive influence. The use of the agile tools alone during the production process caused a loss of 107, 493.165 value. The Taguchi combined lean and Agile simulation data result reveals that performance improvement increased from 47.10 to 122.023, which gave a total performance increment of 74.676. Also, lean and agile have a total of 55 interactions among its eleven factors with strong distributive influence that produced a bell-shaped curve. The use of lean and agile tools alone during the production process will cause only a small loss of 2448.877 value. Therefore, based on the performance analysis data above, the study concluded that the use of both lean and agile in new product development manufacturing of temperature measuring instruments used in the hospital offers better improvement performance, efficiency, and effectiveness than either single tool of lean or Agile. The C_p and C_{pk} for lean and agile combined is 5576.269 (Fig 4.19), the C_p and C_{pk} for a single lean is 151.765 (fig 4.4), and the C_p and C_{pk} for agile is 89.362 (fig 4.11) . The result comparativeness of the C_p and C_{pk} in lean and

agile reveals that the use of lean and agile combination has better process capability to support both stable and turbulent market environment as customization increases than using single lean tool or agile tool.

4.5 Analysis of the Research Question

The simulation outcome answered the study's research question (RQ1). The research question is: "Does lack of engineering integration of lean and agile processes cause underperformance of a product to satisfy customer changing requirements in a global market environment of the 20th century?". The simulation result of lean and Agile integration revealed that the total performance improvement for both lean and agile as a single tool was 74.92 with a loss value of 2448.877. Also, using a single lean tool alone gives a total improvement of 43.623 with a loss value of 77,923.566, and using the Agile tool alone gives a total improvement performance of 39.02 with a loss value of 107,493.165. The performance result of using both lean and agile tools answers the research study question by showing that a single tool of either lean or agile is a leading cause of underperformance that causes a huge amount of loss. The underperformance of a product to satisfy customer changing requirements is caused by a lack of engineering integration of lean and agile because a single tool of lean or agile cannot manage both total cycle time and total lead time as the volume of customization continuously increases, which is the leading cause of new product development underperformance in a global market environment where technology evolves and globalization spreads (Manson-Jones & Towill, 1999; Khalaf & Kadhim, 2020; Roy, 2001; Varl et al., 2020). The simulation revealed data result shows that the integration of lean and agile reveals its capability to manage both the total cycle time and total lead time based on its process capability (C_p and C_{pk}) of 5576.269 which is higher than single lean tool process capability of 151.765 or agile process capability of 89.362. Therefore, the use of combined lean and agile as a single tool offers more efficiency and effectiveness in production management than a single lean or agile tool. The study found that the integration of lean and agile tools can successfully manage a turbulent market environment that creates huge total cycle time and total lead time as customization continues to increase, which leads to product market underperformance that does not satisfy customer satisfaction requirements (Manson - Jones & Towill, 1999; Khalaf & Kadhim, 2020; Varl et al., 2020).

4.6 Analysis of the Hypothesis test

The first hypothesis test Null (H_0) is: Lack of existing Systematic methodology to integrate lean and agile successfully during product development is the leading cause of waste that causes redundancy, obsolescence, and abandonment, and the alternative (H_a) is: Use of a systematic methodology to integrate lean and agile into new product development will help the firm to adapt

both stable and unstable market environment that will reduce waste of all forms. Moreover, the hypothesis testing of the study used statistical analysis of ANOVA using the data obtained from the Taguchi design of the experiment statistical data to test hypothesis 1 result. The result of single lean represent as (μ_1), single Agile (μ_2), and combined lean and agile (μ_3) as a single tool result consists of three means (μ_1 , μ_2 , & μ_3). Therefore, Spatz, 2019 held that for ANOVA testing, $\mu_1 = \mu_2 = \mu_3$. then the null will be accepted. Having that information $\mu_1 = \mu_2 = \mu_3$ then the Null hypothesis (H_0) is represented as $\mu_1 = \mu_2 = \mu_3$ (All population means are the same or equal) and H_a : $\mu_1 \neq \mu_2 \neq \mu_3$ will be accepted which implies that the three means are not all equal. Also, Meng & Yang, 2023 held that process capability (C_{pk}) = $\text{Min} \{ (USL - \mu) / 3\sigma, (\mu - LSL) / 3\sigma \}$ Equation 1 where C_{pk} = process capability index (it measures the capability to produce output to its overall specification), LSL = Lower specification limit, USL = upper specification limit, and σ = standard deviation. Having that the mean value of lean = μ_1 , mean value of Agile = μ_2 , and mean value of combined lean and agile = μ_3 . Then proceeding mathematically with equation 1, $C_{pk} (3\sigma) = \text{min} (USL - \mu)$ or $C_{pk} (3\sigma) = \text{min} (\mu - LSL)$. Therefore, using the lower limit side of the equation for a positive outcome since lean is not statistically negative, then rearranging the equation to obtain $C_{pk} (3\sigma) + LSL = \mu$. Therefore, mean (μ) = $C_{pk} (3\sigma) + LSL$ equation 2. The product of equation two will be used to obtain the value of μ_1 , μ_2 & μ_3 , and the statistical test of hypothesis 1 will be tested, and verified after obtaining of μ_1 , μ_2 & μ_3

$$\text{Mean for Lean } (\mu_1) = C_{pk} (3\sigma) + LSL = 151.765 (3 \times 0.967) + (-2.684) = 437.59$$

Where $C_{pk} = 151.765$ (Fig 4.4), $\sigma = 0.967$ (Fig 4.4) & $LSL = -2.684$ (Fig 4.4)

$$\text{Mean for Agile } (\mu_2) = C_{pk} (3\sigma) + LSL = 89.362 (3 \times 0.971) + (-2.68) = 257.63$$

Where $C_{pk} = 89.362$ (Fig 4.11), $\sigma = 0.971$ (Fig 4.11) & $LSL = -2.68$ (Fig 4.11)

$$\text{Lean and agile } (\mu_3) = C_{pk} (3\sigma) + LSL = 5576.269 (3 \times 0.799) + (-2.42) = 13,363.897$$

Where $C_{pk} = 5576.269$ (Fig 4.17), $\sigma = 0.799$ (Fig 4.17) & $LSL = -2.42$ (Fig 4.17)

The Null hypothesis (H_0) result above reveals that: $\mu_1 = \mu_2 = \mu_3$ are not equal. Therefore, the H_0 will be rejected, and the alternative (H_a) will be accepted. The study can hold that using a systematic methodology to integrate lean and agile into new product development will help firms adapt to both stable and unstable market environments that will reduce waste of all forms. The lean and agile integrated single tool has $CP_k = 5576.269$, which is much higher than either single lean or agile tool, showing the process capability has high effective efficiency to reduce both lean and agile waste activities. Moreover, the higher process capability of combined lean and agile (CP_k) =

5576.269 showed that the combination of lean and agile offered better ability to produce a product within a customer's defined tolerance range which fits customer changing requirements with minimum loss than a single tool of lean or agile that produce huge loss. Therefore, the study can justify that alternative (Ha1) is acceptable, and integration of lean and agile into new product development will help a firm adapt to both stable and unstable market environments that will reduce waste of all forms, which satisfies customer changing requirements as technology evolves and globalization spreads.

The Second hypothesis Test (H02): Lack of existing systematic methodology to integrate lean and agile successfully is associated with inefficiency and ineffectiveness in the management of push, which is lean thinking, and pull, which is agile thinking strategy during new product development. (Ha2): Use of a systematic methodology to integrate lean and agile into new product development positively removes all forms of waste during the management of a push and pull strategy that supports high efficiency and effectiveness that fits customer satisfaction and expectation.

Having that Mean for Lean (μ_1) = $Cpk (3\sigma) + LSL = 151.765 (3 \times 0.967) + (-2.684) = 437.59$

Where $Cpk = 151.765$ (Fig 4.4), $\sigma = 0.967$ & $LSL = -2.684$

Mean for Agile (μ_2) = $Cpk (3\sigma) + LSL = 89.362 (3 \times 0.971) + (-2.68) = 257.63$

Where $Cpk = 89.362$ (Fig 4.11), $\sigma = 0.971$ & $LSL = -2.68$

Lean and agile (μ_3) = $Cpk (3\sigma) + LSL = 5576.269 (3 \times 0.799) + (-2.42) = 13,363.897$

Where $Cpk = 5576.269$, $\sigma = 0.799$ & $LSL = -2.42$. The Null hypothesis (H02) result above reveals that: $\mu_1 = \mu_2 = \mu_3$ are not equal. Therefore, the H02 will be rejected since the means are unequal, and the alternative (Ha2) will be accepted. The study can hold that using a systematic methodology to integrate lean and agile into new product development removes a huge amount of waste that comes as a loss of only 2448,877 (unlike a single lean that has a loss of 77,923.566 and a single agile loss of 107, 493.165) when managing a push-and-pull strategy that supports efficient and effective customer satisfaction and expectation. The lean and agile integrated single tool has $CPK = 5576.265$, which is much higher than either single lean or agile tool, which shows high efficiency of the process capability to manage push and pull strategy. Moreover, the $Cpk = 5576.265$ reveals that the process capability is efficient and effective in managing the turbulence in both push and pull strategies that conform to customer requirements.

Third hypothesis Test (H03): The non-existent use of systematic methodology to integrate lean and agile successfully creates increased complexities and inefficiencies in managing total zero cycle

time and zero lead time. (Ha3): Use of an appropriate systematic methodology to integrate lean and agile into new product development removes complexities, and inefficiencies, and simplifies how to manage firm resources during value creation that will positively manage zero total cycle time and zero lead time that fit customer changing requirements.

Having Mean for Lean (μ_1) = $Cpk(3\sigma) + LSL = 151.765(3 \times 0.967) + (-2.684) = 437.59$

Where $Cpk = 151.765$ (Fig 4.4), $\sigma = 0.967$ & $LSL = -2.684$

Mean for Agile (μ_2) = $Cpk(3\sigma) + LSL = 89.362(3 \times 0.971) + (-2.68) = 257.63$

Where $Cpk = 89.362$, $\sigma = 0.971$ & $LSL = -2.68$

Lean and agile (μ_3) = $Cpk(3\sigma) + LSL = 5576.269(3 \times 0.799) + (-2.42) = 13,363.897$

Where $Cpk = 5576.269$, $\sigma = 0.799$ & $LSL = -2.42$. The Null hypothesis (H03) result above reveals that: $\mu_1 = \mu_2 = \mu_3$ are not equal. Therefore, the H03 will be rejected since the means are unequal. The alternative (Ha3) will be accepted. The study can uphold that using an appropriate systematic methodology to integrate lean and agile into new product development removes complexities, and inefficiencies and simplifies management of a firm resources using a structured step-by-step process during value creation, which will positively manage zero total cycle time and zero lead time that fit customer changing requirement. The lean and agile integrated single tool has $CP_k = 5576.269$ with less loss of 2448.877, which is much better than either the single lean tool of CP_k of 151.765 with a huge loss of 77,923.566 or single agile tool of CP_k of 89.362 with huge loss of 107,493.165. The simulation data result showed that lean and agile integration as a single tool offers excellent process capability to manage a structure step-by-step approach that eliminates complexities and inefficiencies than either a single lean tool or agile tool. Moreover, the combination of lean and agile as a single tool has process capability $CP_k = 5576.265$ with little loss of 2448.877 which shows the capability to manage complexities that are inevitable as turbulence increases during high-volume customization that occurs when technology evolves and globalization spreads.

4.7 Summary of the Study chapter

Chapter four focuses on data design analysis with emphasis on data collection design and procedure, data analysis plans and procedure, measurement and instrumentation, reliability of the data, validity of the data, statistical engineering approach, flexibility application, continuous improvement application, transient competitive applications, risk and reliability application, global market application. Also, it discloses how data will be collected and processed using the Taguchi approach and inferential ANOVA calculation. Chapter four also reveals how the data can be analyzed and

applicable to different areas of human endeavor to show the unique relevancy of the study. The experimental design process will use Taguchi orthogonal arrays. The Taguchi experiment orthogonal array was designed based on the combination of Latin squares first invented by Euler (Roy, 2001). The Taguchi simulation result shows that the integration of lean and agile is capable to manage both the total cycle time and total lead time based on its process capability (C_p and C_{pk}) of 5576.269 which is higher than single lean tool process capability of 151.765 or agile process capability of 89.362. The practical significance of C_p and C_{pk} is that it informs a production manager on how to select lean and agile integration based on target to obtain higher c_p and c_{pk} that will remove more cycle waste and lead time. The C_p and C_{pk} also help the production manager to estimate and minimize economic waste coming from cost of quality at any performance level (Roy, 2001).

CONCLUSION AND RESEARCH RECOMMENDATION**Introduction**

The Taguchi process improvement simulation study data results showed that losses that result from waste that causes underperformance are inevitable as globalization and technology continue to evolve regardless of the type of tool used. Therefore, the study concluded based on the data obtained, that using engineering integration of lean and agile tools as a single tool will help to eliminate loss to a value of 2448.877, which is relatively smaller when compared with lean with a loss of 77,923.566 value or Agile tool loss that amount to 107, 493.165. Moreover, the effect of technology evolution and globalization is the leading cause of high-volume customization that automatically creates total cycle time waste and total lead time waste during new product development (Furlan et al., 2023; Manson-Jones & Towill, 1999; Varl, 2020). The study result shows that the effect of both different types of waste (total cycle time and total lead time) during the process is inevitable so the need to reduce this waste is necessary to prevent product underperformance that fits customer-changing requirements (Furlan et al., 2023; Manson - Jones & Towill, 1999; Varl, 2020). The study simulation result also shows that underperformance comes in different forms, which is the leading cause of most manufacturing firm`s extinction after experiencing huge losses from waste during the new product development process. The study data result shows that the amount of loss for using a single lean tool or agile tool makes it relevant to support the growing need for integration of lean and agile as a strategic requirement to eliminate huge amounts of waste from highly turbulent market effects and high-volume customization caused by both technology evolvment and globalization spread that leads to losses.

5.1 Practical Assessment of Research Question Analysis

The outcome of this study revealed that lack of engineering integration of lean and agile as a single tool is the leading cause of underperformance of new product development to satisfy customer-changing requirements in a global market environment of today because technology evolves as well as globalization that creates waste/loss. The rapid evolution of technology and globalization is the leading cause of high-volume customization which causes high-volume variation that causes a turbulent market that causes environmental complexities that a single tool of lean or agile cannot handle to fit customer changing requirements, and this leads to losses (Furlan et al., 2023; Varl, 2020). The Taguchi simulation loss result reveals that integration of lean and agile will help to produce better quality and efficient products that fit the customer-changing environmental requirement. The Taguchi simulation study results of loss for the case study when using either lean

tool (loss= 77,923.566) or Agile tool (loss = 107,493.165) shows that a single tool of either lean or agile does not fit the market environment of today that is continuously increasing in volume of customization as customer requirement increases as new technology evolves, and this is among the significant leading cause of waste that lead to losses.

5.2 Practical Assessment of Hypothesis test Analysis

The practical implication of the hypothesis based on the generated results in the calculation of financial relationship loss reveals that successful lean and agile integration applications in new product development will help a manufacturing firm to reduce inevitable waste from total cycle time and total lead time to a loss value of 2448.877 which is very minimal when compared with a lean tool that has loss of 77, 923.566 and agile with a loss value of 107, 493.165. The simulation study data result shows that using either a single lean tool or an Agile tool is the leading cause of underperformance, which results in all forms of waste during the production process. The idea of using a single tool of either lean or agile will negatively impact the manufacturing ability to manage both lean and agile activities that are involved during the production process because a single lean or Agile tends to have poor limited interaction distributive influence that creates more waste that leads to huge loss. The case study's Cpk from the Taguchi simulation shows that both lean and agile as a single tool display a highly efficient and effective amount of capability of 5576.265 to manage both turbulent and stable market environments when compared with either lean value of 151.765 or agile process capability value of 89.362. The study simulation outcome reveals that any production industry of today that uses a single tool of either lean or agile will continue to find it difficult to sustain the increasing high-volume customization that exists in different market environments of today which inevitably results in huge losses that originate from higher complexities from customization. The Taguchi study on improvement simulation outcome shows that the amount of loss will be difficult to manage by a single tool of lean or agile to fit customer changing requirements in a current highly dynamic market of the 20th century.

5.3 Supplementary Findings

The outcome of the Taguchi design of the experiment makes it relevant for the study to uphold that the application of lean and agile in the production process will help to reduce total cycle time and total lead time, which are the leading causes of waste that cause underperformance and inefficiencies that cause huge losses that can force a firm to experience extinction. The outcome of the Taguchi experiment from the ANOVA simulation results reveals that the combination of lean and agile factors shows a significantly high number of interaction distributive influences in managing waste reduction. The significant interactive distribution

influence is the reason why only the combination of lean and agile generates a bell shape. Moreover, the variation reduction plot of a bell shape reveals both lean and agile activities were substantially captured and improved using the lean and agile manufacturing process of new product development of temperature measuring equipment used at the hospital for patient health care management. Moreover, the ANOVA of a single tool of lean shows that most factors were not substantially captured, and a lot of factors were technically redundant, which reveals that there were inefficiencies in using only lean because the variation/waste reduction plot shows poor factor distributive influence with a small number of interactions. Also, the ANOVA of a single tool of agile shows inefficiencies because most agile factors were redundant without significant contributions made by most of the factors. This technically revealed that waste reduction activities are not properly distributed and a small number of interactions also supports poor factor distribution. The study of the ANOVA combination of lean and agile tools offers the advantage of reducing both total cycle time waste and total lead time waste because of high multiple-factor interaction that produces a high distributive influence on the production process. The ANOVA statistical result also revealed that the percentage of individual contribution showed that every activity contributes to the sum of waste elimination during new product development, which a single tool cannot offer. The amount of loss incurred using lean and agile amounts to 2448.877 which is very little when compared with using a single lean tool that has a loss value of 77,923.566 or an agile tool that has a loss value of 107,493.165. Moreover, the size of the loss in value from the study must be taken into consideration during the selection of production management strategy to increase efficiency and effectiveness that can withstand high volume customization that creates complexities in managing 20th-century customer changing requirements.

5.4 Conclusion

The outcome of the Taguchi design of the experiment study strongly revealed that the application of lean and agile as a single tool in manufacturing helps to reduce total cycle time and total lead time with the least loss when compared with either single lean or agile. The idea of using a single tool is the leading cause of waste that causes underperformance and inefficiencies that lead to all forms of waste etc. The study reveals that most of the problems of waste, loss, and firm market extinction are the resultant effect of not using both lean and agile as a single tool because a single tool cannot fit customer changing requirements during high volume customization that is inevitable as technology evolves and globalization spreads. The study concluded that the 20th-century market tends to have high velocity because of the

rapid effect of globalization and technological evolvement. This phenomenon of high velocity is inevitable, and it attracts high-volume customization that only the application of lean and agile as a single tool can handle. The Taguchi simulation study concluded that the speed of innovation requires both a pull and push strategy based on the data observation to manage both stable and unstable market environments. Moreover, it is inevitable for a firm to survive and grow successfully without the application of lean and agile as a single tool to manage total cycle waste and total lead time waste with little loss in the modern market environment. The study concluded from the data simulation result that the use of a single tool is the leading cause of underperformance. Also, the study based on the Taguchi result concluded that only the application of lean and agile as a single tool can help a firm manage the effect of disruptive strategy which results from the turbulent market environment used by competitors to cause market redundancy, obsolescence, abandonment, etc. against competitors. The study found that the impact of high-volume customization is the leading cause of losses that lead to product underperformance. The study concludes that only the application of lean and agile tools as a single tool will manage the effect of high-volume customization that will continue to increase as globalization spreads and technology evolves to create new business opportunities.

5.5 Research Recommendation for Future Studies

The research recommends further studies in the context of digital science to understand if artificial intelligence (AI) will have a strong impact on improving the integration of lean and agile as market customization continues to increase in size as technology and globalization increase. The recommendation will help to support many emerging market environments to catch up with the increasing speed of complexity as the volume of customization increases. The study also recommends that the academic community needs to invest in further research to understand if artificial intelligence (AI) will have a strong impact on improving the selection criteria speed which can be crucial to support further lean and agile application innovation. The paper is only limited to the lean and agile application process but AI is recommended for new innovation that could possibly support faster lean and agile tool selection.

5.6 Summary of the Study chapter

Chapter five focuses on conclusion and research recommendation with emphasis on hypothesis one test and conclusion, hypothesis two test and conclusion, hypothesis three test and conclusion, Research conclusion, and research recommendation. Chapter Five reveals the relevance of the study to prove the validity and reliability of hypothesis one, hypothesis two, and hypothesis three through

statistical tests and deductive logic. The ANOVA statistical result also revealed that the percentage of individual contribution showed that every activity contributes to the sum of waste elimination during new product development, which a single tool cannot offer. The amount of loss incurred using lean and agile amounts to 2448.877 which is very little when compared with using a single lean tool that has a loss value of 77,923.566 or an agile tool that has a loss value of 107,493.165. The studies recommends that the academic community needs to invest in further research to understand if artificial intelligence (AI) will have a strong impact on improving the selection criteria speed which can be crucial to support further lean and agile application innovation. The paper is only limited to the lean and agile application process but AI is recommended for new innovation that could possibly support faster lean and agile tool selection.

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