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Lean and Value Engineering Hybrid Methodology: Establishing a Selection Framework

Nosipho Gumede

(Student number: 452699)

School of Mechanical, Industrial and Aeronautical Engineering

University of the Witwatersrand

Johannesburg, South Africa.

Supervisor: Dr T.S. Hattingh

A Research Report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Science in Engineering.

Date: 13 February 2020

Declaration

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

_____

Nosipho Gumede

13th day of February 2020

Abstract

Background: The evolution of Continuous Improvement methodologies is manifest in several ways: formalisation of activities, spread across disciplines and the formation of hybrid methodologies. The focus of this research was in the third mode of evolution, hybrid methodologies – specifically, the hybrid methodology formed by combining Lean and Value Engineering.

Purpose: This study explored the implementation of Lean and Value Engineering via three types of models, namely Interchangeable Use, Concurrent Use and Integrated Use models. The objectives of this study were to determine the variations of Interchangeable, Concurrent and Integrated Use models that are present in Lean and VE hybrid methodology literature, determine the principles that are associated with these three types of models and establish a model selection framework based on the model principles.

Methodology: The objectives of this study were achieved by employing a Systematic Literature Review Methodology (SLRM). The SLRM search strategy involved the search of both grey and peer-reviewed literature using four search methods (free-text, manual, citation and bibliographic searching) to locate relevant papers from 17 multidisciplinary literature sources. 12 481 retrieved records were screened by title, 292 were screened by abstract and 82 papers were screened using full-text screening methods. The application of a set of the *inclusion/exclusion* criteria resulted in the selection of 24 relevant papers. These papers were analysed and classified by sector, author profession, publisher and document type. Furthermore, the papers were critically appraised based on applicability, validity and reproducibility factors.

Findings: The results analysis revealed that the majority of the included research was conducted in the manufacturing industry and the majority of the papers were written by academics. A total of 26 (2 Concurrent, 3 Interchangeable Use, and 21 Integrated Use) hybrid models were obtained and analysed. The analysis resulted in 31 findings, these findings were utilised to develop a Lean and VE hybrid model selection framework. The established framework does not only guide decision-making but it also indicates the types of initiatives that the models can be *selected* for, the *order* in which Lean and VE model components can be arranged, the areas and conditions in which the models can be *utilised* and the *purpose* that can be achieved through the model application. The framework structure is comprised of coded attributes that make it adaptable to Multi-Criteria Decision Methods and digitalization.

Contribution: This research is valuable to researchers, scholars, and practitioners. It reports on the current state of the body of knowledge on Lean and VE hybrid methodology, it proposes a hybrid selection model that is intended to guide implementation and facilitate empirical research, and it adds structure to Lean and VE hybrid methodology implementation by proposing a systematic approach for hybrid model implementation.

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1 Introduction

1.1 Background

Continuous improvement is defined as the advancement of organisational performance through a planned, organised and systematic approach (Gonzalez Aleu & Van Aken, 2016). The evolution of Continuous Improvement (CI) initiatives has manifested in several ways, one of which is formalisation. The first evidence of CI initiatives dates back to the 1800s where informal employee-driven improvements were encouraged and remunerated by management through reward schemes (Bhuiyan & Baghel, 2005). In the late 1800s and early 1900s, these CI initiatives underwent a process of formalisation when scientific methods were employed to solve production problems (Singh & Singh, 2015). It was after World War II that the manufacturing industry pioneered two recognised CI methodologies, namely Lean (Toyota Production System) and Value Engineering (Lane Davis, 2004; Lean Enterprise Institute, 2000). Lean and Value Engineering are methodologies which consist of jargon and concepts that make them distinguishable. The progression from the informal, small-scale employee-driven methods of the 1800s to today's distinguishable Lean and Value Engineering (VE) methodologies is evidence of CI's evolution through formalisation.

Further evidence of CI's evolution is its spread to other sectors - the application of Lean and VE methodologies originated in the manufacturing industry, but it has not remained there. There is published evidence of the application of Lean in the South African manufacturing, mining, healthcare, education, logistics and construction industries (Dondofema et al., 2017). It has been proposed that Lean can be applied anywhere because of the methodology's focus on the process instead of output (Haque & Chaudhuri, 2015). In the same manner, VE has also established its presence in a number of sectors. VM Services, a South African company that applies VE to solve problems, has spread value methodology from manufacturing to mining, retail, banking and construction (VM Services, 2019).

Lastly, the evolution of CI is evident in the creation of hybrid methodologies. A hybrid methodology is formed when individual CI methodologies are combined to realise benefits that are greater than those offered by one method (Bhuiyan & Baghel, 2005; Singh & Singh, 2015). Lean Six Sigma, a combination of Lean (minimises production waste) and Six Sigma (uses statistical methods to ensure quality), is a widely accepted CI hybrid methodology (Bhuiyan & Baghel, 2005). A less common hybrid methodology is a combination of Lean and VE. Although Lean Six Sigma is widely accepted, it is argued that the development of this hybrid methodology lacks a single approach that effectively combines Lean and Six Sigma (Pepper & Spedding, 2010). Conversely, the authors of Lean and VE hybrid methodology literature typically follow similar development approaches (Cell & Arratia, 2003; Nayak, 2006; Shekari & Fallahian, 2007; Mandelbaum et al., 2010; Musa et al., 2016; Ekanayake &

Sandanayake, 2017). These approaches can be summarised using three main steps (Illustrated by Figure 1):

- A discussion of Lean and VE theory and practices
- A comparative analysis of Lean and VE concepts that leads to the identification of strengths, weaknesses, similarities and differences of two individual methodologies
- The implementation of Lean and VE hybrid methodology through various models

The authors of Lean and VE hybrid methodology literature utilise different terms to describe implementation models. Cell & Arratia (2003) propose that this hybrid methodology can be implemented via *concurrent* and *integrated* models. On the other hand, Nayak (2006) states that implementation can be done through *connected/interdependent* and *concurrent* models. Additionally, some authors claim that the existence of similarities can be used to justify *interchangeable* models (Nayak, 2006; Musa et al., 2016). The authors utilise terms such as concurrent, interchangeable, interdependent and integrated but do not provide distinct definitions for the terms. Furthermore, some authors use the term *integrated* to describe all model types (Ho et al., 2000). The lack of definitions and the use of blanket terms creates ambiguity. This research proposes that there are three main models that can be utilised to apply Lean and VE hybrid methodology, and these models are defined as follows (illustrated in Figure 1):

- Interchangeable Use models: the employment of either Lean or VE (or their components) in a substitutional manner. Lean and VE are applied separately and are mutually exclusive. (Nayak, 2006; Musa et al., 2016)
- Concurrent Use models: the simultaneous application of individual Lean and VE (or their components). Lean and VE are applied separately and are mutually inclusive. (Cell & Arratia, 2003; Nayak, 2006)
- Integrated Use models: the sequenced implementation of amalgamated Lean and VE (or their combined components). Lean and VE connected, interdependent and form a coherent whole. Lean and VE are applied together through a merged structure. (Nayak, 2006; Cell & Arratia, 2003; Ekanayake & Sandanayake, 2017; Mandelbaum et al., 2010)

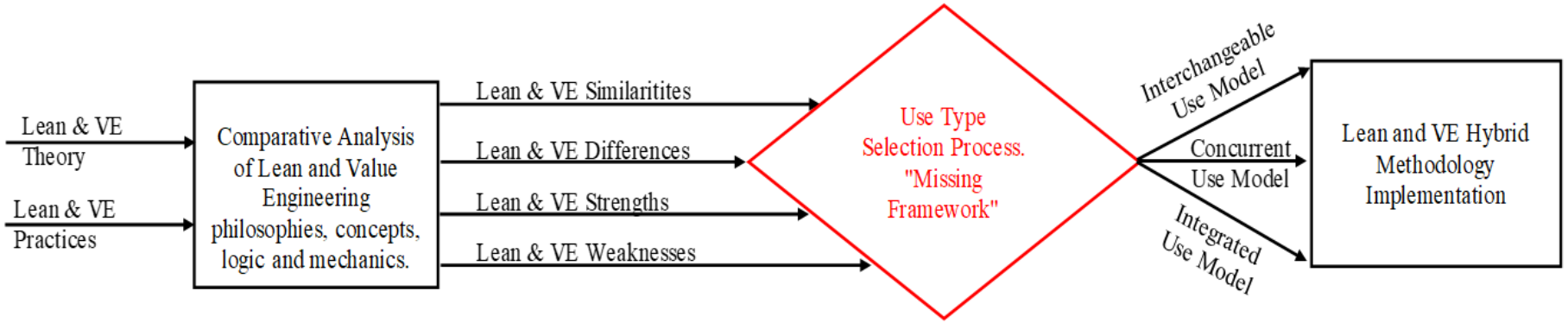


Figure 1: Proposed Lean and VE hybrid methodology development process

The diamond shape in Figure 1 illustrates the motivation for this study, this is discussed further in section 1.2.

1.2 Problem Statement

The authors of Lean and VE hybrid methodology literature propose diverse ways in which it can be applied: some propose that gains can be attained through Concurrent and Integrated Use models (Nayak, 2006; Cell & Arratia, 2003), while others propose Integrated Use models only (Mandelbaum et al., 2010; Ekanayake & Sandanayake, 2017; Shekari & Fallahian, 2007), and still others propose that Lean and VE similarities can be used to justify Interchangeable Use (Nayak, 2006; Musa et al., 2016). The suggestion of Interchangeable Use, Concurrent Use and Integrated Use models is not accompanied by a formalised framework that guides a model selection process (as illustrated by the diamond shape in Figure 1). Practitioners are instructed to establish the advantages and disadvantages of Lean and VE within the context of their own organisation's products, processes and objectives (Nayak, 2006), but are not provided with a guiding framework that can assist in the determination of model type suitability.

The assertion of this research is not that the authors of Lean and VE hybrid methodology do not provide frameworks, it is that they do not offer comprehensive frameworks that account for the three types of models. This is evident in literature where some authors (Shekari & Fallahian, 2007) provide a framework (presented as an algorithm) for the implementation of Integrated Use models only; a framework that places emphasis on the operational phases of implementation and the sequencing of Lean and VE hybrid methodology activities. The framework provided by Shekari & Fallahian (2007) is incomplete because it does not account for Interchangeable and Concurrent Use models. Further evidence of a framework proposal can be found in the literature presented by Nayak (2006). The Nayak (2006) framework depicts the convergence possibilities of Lean and VE based on focus, approach, techniques and activities, but does not illustrate how the three implementation models relate to the convergence possibilities. The lack of a comprehensive framework is the main motivation for this study, a comprehensive framework is one that not only accounts for the three types of models but also guides a model type selection process.

A guiding framework is one of the critical success factors for Lean and Value Engineering implementation (Haque & Chaudhuri, 2015; VM Services, 2017). A selection framework will enable reproducibility, which is a key driver of implementation (Shokraneh, 2019) . Implementation will offer the required evidence to advance research within Lean and VE hybrid methodology. Lean and VE hybrid methodology is an emerging research area, and thus this study is deemed necessary because it aims to establish a selection framework that will enable future research and facilitate implementation within industry.

Research Questions

It has been proposed that there is an opportunity to benefit from the implementation of Lean and Value Engineering hybrid methodology. However, no framework exists to guide the selection of either Interchangeable, Concurrent and Integrated Use models. It follows that the main research question for this study is:

What framework can provide guidance for the selection of either Interchangeable, Concurrent or Integrated Use models in Lean and VE hybrid methodology?

This question is satisfied by answering the following sub-questions:

- What variations of Interchangeable, Concurrent and Integrated Use models exist in Lean and VE hybrid methodology literature?
- What guiding principles are evident in the development of Lean and VE hybrid methodology models?
- What model selection framework can be produced from these guiding principles?

1.3 Research Objectives

The outlined research questions are addressed to achieve the following objectives:

- Determine the variations of Interchangeable, Concurrent and Integrated Use models that are present in Lean and VE hybrid methodology literature
- Determine the principles that are associated with Interchangeable, Concurrent and Integrated Use models
- Establish a model selection framework based on these principles

1.4 Research Method Summary

To achieve the objectives of this study, it was deemed necessary to employ a research method that facilitates the development of a generalizable framework. It was concluded that at Masters level, Systematic Literature Review Methodology (SLRM) offers the benefits of large-scale primary research that enables the development of a more generalizable framework (Boland et al., 2017). This reasoning led to the selection of the SLRM. The relationship between the selected research method and the research objectives is illustrated by Figure 2. The SLRM followed is composed of a 9-phase process (Bearman et al., 2012):

- Phase 1: The establishment of a review question
- Phase 2: The development of *inclusion/exclusion* criteria
- Phase 3: The formation of a search strategy
- Phase 4: The screening of literature

- Phase 5: The reporting of literature search strategy results
- Phase 6: The critical appraisal of included studies
- Phase 7: The extraction of data from the included studies
- Phase 8: The synthesis of the extracted data
- Phase 9: The conclusion

This 9-phase process was applied and documented to ensure that the systematic review is explicit, comprehensive and reproducible.

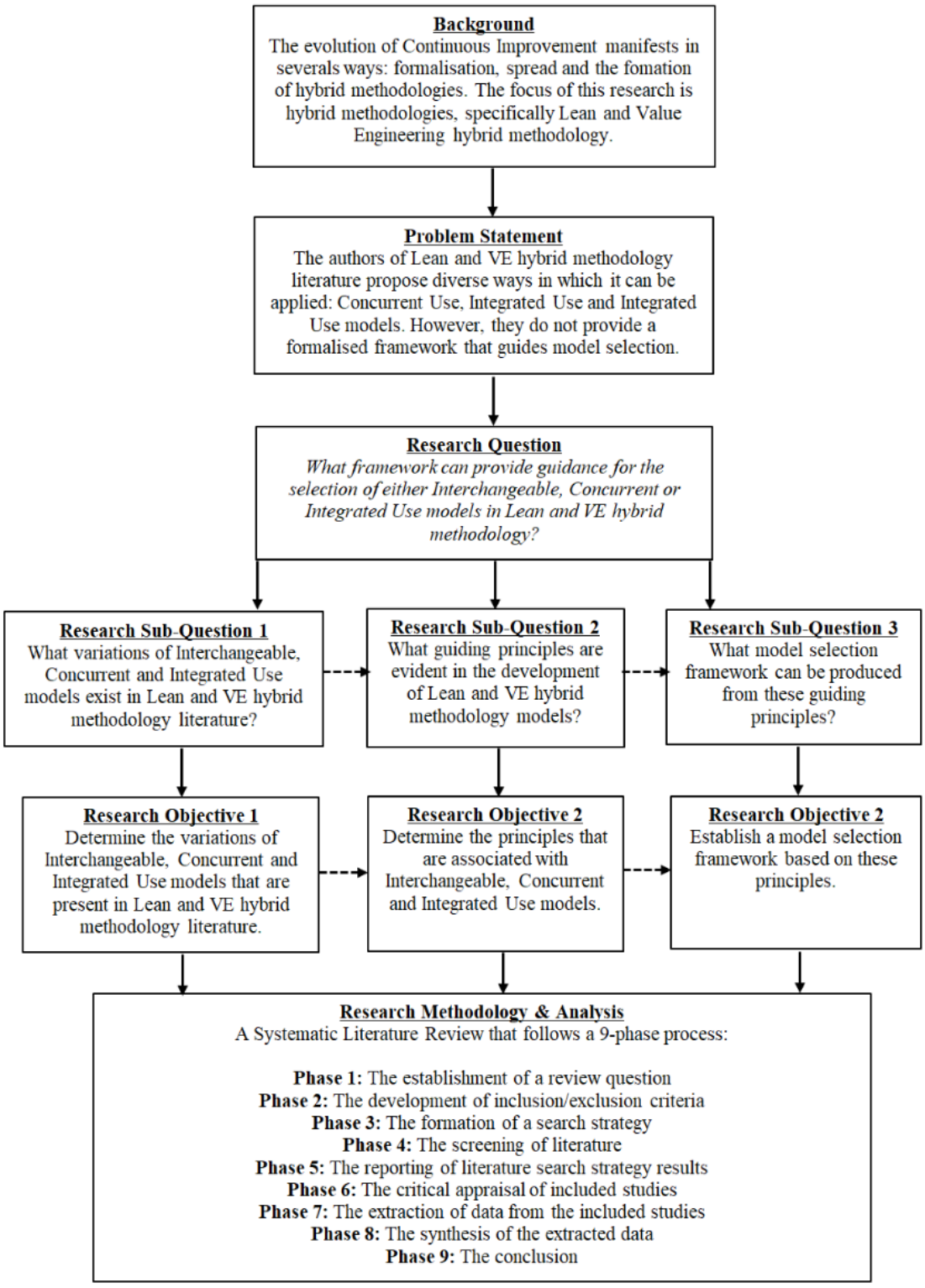


Figure 2: Relationship Flow Diagram

1.5 Ethics

The study involves the employment of publicly available data; it does not include human materials, human sources or company data and therefore imposes no ethical risk. An ethics waiver was sought and received from the School of Mechanical, Industrial and Aeronautical Engineering, the ethics clearance number for this research is MIAEC 047/19w.

1.6 Assumptions, Limitations and Scope

1.6.1 Assumptions

This research follows a qualitative approach and is therefore based on a paradigm assumption that is often associated with Qualitative Research (Simon, n.d.). This assumption is as follows:

- The reviewed research is influenced by context, however, patterns can be analysed and interpreted to provide explanations for phenomena and theory.

Additional assumptions (which are specific to this research) are as follows:

- All the important research components are sufficiently captured in the published articles
- The differences in length and structure of various document types (theses/journal articles/reports) have a negligible effect on the representativeness of published data

1.6.2 Limitations

The design of this study was subject to limitations. The three main constraints that influenced the limitations of this study were time, cost and data access. The synthesized literature was limited by the following:

- The *inclusion/exclusion* criteria that were employed based on three requirements: 1) the literature must be written in the English language, 2) the literature must include a discussion of both Lean and VE, and 3) the literature must include a logical Lean and VE hybrid methodology development process depicted by Figure 1.
- The structure, information and biases contained in grey literature.
- The format of published articles that limits the length of documents and therefore limits access to information.
- The number of data sources utilised to locate the literature (these include Scopus, Emerald Insight, Wiley Online, Taylor and Francis, ProQuest Central, Google Scholar, SAGE Premier Online, Web of Science, Grey Net, ProQuest Dissertation and Theses, Research Gate, World-Cat Dissertations and Theses, Digital Archive of Theses and Dissertations including Current and Completed Research, SAVE International Conference Proceedings, Institute of Value Management Australia Website, Hong Kong Institute of Value Management Website and the

Lean Enterprise Institute Knowledge Center web page). Only 17 literature sources were searched due to access, time and cost constraints.

1.6.3 Scope

The main aim of this study was to establish a model selection framework suitable for the implementation of Lean and VE hybrid methodology, the empirical validation of the framework was beyond the scope of this study. Moreover, it is acknowledged that the proposal of a Lean and VE hybrid methodology is based on a comparative analysis of the two methodologies. However, this study is not aimed at contrasting Lean and VE. It is recognised that the words model and framework are sometimes used synonymously but, for the purpose of this study they are defined as follows:

- A framework is or contains a structure/system for the realisation of a defined goal (Verbrugge, 2016). It is a provision of answers for "how to" questions that guides methodology implementation (Chay et al., 2015).
- A framework comprises of one or more models (Verbrugge, 2016). Models are generalised or hypothetical descriptions used to present, analyse or explain something (Booth & Carroll, 2015).
- Concepts are the primary components of theory, a framework is a structure utilised to represent these components (Booth & Carroll, 2015).

1.7 Outline of Chapters

The purpose of Chapter 1 is to introduce the study. This objective is achieved by presenting a background that outlines the context of the study and a problem statement that details the motivation for this study. Furthermore, this section consists of the research questions, research objectives, a summary of the research method, ethics and limitations. These elements describe why and how this study was conducted.

After introducing the study, relevant literature is reviewed in Chapter 2. The discussions are categorised using four headings namely, Lean and VE: Individual Methodologies, Lean and VE Hybrid Methodology, Lean and VE Hybrid Methodology Models, and Frameworks in Lean and Value Engineering.

The selected research method is presented in Chapter 3. This section contains descriptions of the study design, data collection methods, data analysis methods and an outline of the methods that were applied to ensure research quality.

Chapter 4 contains an overview of the selected research articles. The selected articles are introduced and classified (by sector, author profession, publisher and document type). Additionally, this section includes the analysis of the critical appraisal results.

The results are presented and analysed in Chapter 5. This chapter includes an examination of the Lean and VE theory and practices found in hybrid methodology literature, the three types of models utilised in hybrid methodology implementation and the principles of the three model types.
The results are synthesized in Chapter 6. Additionally, the proposed hybrid model selection framework is presented in this chapter.

Chapter 7 details the conclusion of the report, limitations of the study and recommendations for future research. This section is followed by a list of the references and appendices.

2 Literature Review

The main research question "What framework can provide guidance for the selection of either Interchangeable Use, Concurrent Use or Integrated Use models in Lean and VE hybrid methodology?" contains the following themes: Lean, Value Engineering, hybrid methodology, framework development, Interchangeable/Integrated/Concurrent Use models. These themes were utilised to develop the four sections found in this chapter.

The purpose of **Section 2.1**: **Lean and VE: Individual Methodologies** is to review Lean and Value Engineering concepts, provide their definitions and briefly describe their philosophies, tools and techniques.

The aim of **Section 2.2: Lean and VE: Hybrid Methodologies** is to explore the factors and relationships that inform Lean and Value Engineering hybrid methodology theory and to describe the hybrid methodology development process.

After introducing the theory that supports the formation of the hybrid methodology, the models of Lean and VE hybrid methodology are discussed in **Section 2.3: Lean and VE Hybrid Methodology Models**.

Lastly, **Section 2.4: Frameworks in Lean and Value Engineering** includes a review of the literature that describes individual and hybrid methodology frameworks.

2.1. Lean and VE: Individual Methodologies

It is important to first introduce Lean and VE as individual methodologies before presenting the two methods in a hybrid form. Both methodologies originated in the manufacturing industry and are often applied to achieve "value maximisation". The similarity in their origins and objectives often leads to the conclusion that the two methodologies are exactly the same (Nayak, 2006; Musa et al., 2016). This is not the case, Lean and VE have very distinct philosophies, concepts, tools and techniques.

2.1.1. Individual Methodology I: Lean

The Manufacturing Extension Partnership of the National Institute of Standards and Technology, a part of the United States Department of Commerce, provides the following Lean definition:

> A systematic approach in identifying and eliminating waste (non-value adding activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection (Alukal & Manos, 2006, p. 2).

Toyota Production System, Just in Time (JIT) production and Kaizen (Continuous Improvement) are often used as Lean synonyms (Bozdogan, 2010). However, JIT and Kaizen are not true synonyms of Lean, they are techniques that are applied in the implementation of Lean (*Lean Manufacturing Tools*, n.d.). Lean definitions can be separated into two categories: the Old Lean and the New Lean (LeanKit, 2020). The Old Lean is linked with the Toyota Production System. Definitions that are associated with the Old Lean place emphasis on operational excellence within the manufacturing industry and have been criticised for being a group of practices (LeanKit, 2020). On the other hand, the New Lean places emphasis on customer value delivery and continuous improvement, and is comprised of a set of principles which can be applied in various disciplines (LeanKit, 2020). The above definition was selected because it has the characteristics of the New Lean, the New Lean aligns with the multidisciplinary approach of this study.

Unpacking the Lean definition

The Lean definition contains several concepts. These concepts can be grouped into three types: "systematic approach", "tools & techniques" and "value & waste". These three concept groups are used to unpack the Lean definition.

Systematic approach:

The "systematic approach" term contained in the definition is best encapsulated by the five basic principles of Lean. These principles form a logical sequence, as outlined below (Teeuwen, 2011; Womack & Jones, 2003):

- **Specify Value**: This is the first step in the Lean process. The value is specified from the customer's perspective, is designed by the producer and is often articulated in relation to a product or service.
- **Identify the Value Stream**: This step involves the identification of the value stream belonging to a product, product family or service. Additionally, it involves the application of visual analysis to identify waste and value.
- **Create Flow**: This step is applied to minimise batch and queue. After value maximisation and waste elimination, the processes are reconfigured in a manner that maximises flow.
- **Pull from the Customer**: This step is aimed at creating a production rate that minimises waiting and inventory. This is done by ensuring that the production rate is equal to the customers pull. The aim is to create an environment where the production rate is not too slow that is creates waiting and is not too fast that it creates inventory.
- **Pursue Perfection**: This last step captures the iterative characteristic of Lean. Lean improvements are applied continuously with the aim of reaching a perfect state.

Tools and Techniques:

The systematic approach can be implemented using various tools and techniques. These techniques are summarised below (*Lean Manufacturing Tools*, n.d.):

- Standardised Work: The documentation and control of processes and procedures.
- Five S: The five s principles (sort, straighten, sweep, standardise, sustain).
- Total Productive Maintenance: The application of preventative maintenance techniques.
- Six Big Losses: The classification of loss of productivity causes according to six categories, namely breakdowns, setups, stoppages, reduced speed, defects, setup scrap.
- Overall Equipment Effectiveness: The measure of process availability, utilisation, performance and quality in relation to the six big losses.
- Gemba: The visits to the area where the activity/process/work takes place.
- Visual Management: The configuration of activities to create a system that facilitates easy detection of flow and defects.
- Andon: The implementation of alarm systems to signal abnormalities or defects.
- Waste Classification: The categorisation of non-value adding activities into 8 types.
- Heijunka: The minimisation of unevenness or mura.

- Kaizen: The implementation of continuous improvement activities to make incremental changes.
- Kaikaku: The breakthrough kaizen event that is purposed to create substantial change in a short space of time.
- Seven Quality Tools: The tools that include Tally Sheets, Histograms, Pareto diagrams, Ishikawa or Fishbone Diagrams, Process Control Charts, Process Mapping, Brainstorming, 5 Whys and PDCA (Plan Do Check Act).
- Total Quality Management (Total Quality Control): The management philosophy that involves the collaboration of managers, employees and departments to continuously improve the quality of services and products (Lean Enterprise Institute, n.d.).
- Just in Time: The inventory reduction technique that is purposed to ensure that the right number of parts/products/services are pulled at the rate required by the customer or downstream process.
- Pull System: The tool that is used to achieve Just in Time production.
- Kanban System: The tool that is used to control the Pull System through the application of cards, containers or physical spaces to signal stocking or production requirements.
- Cellular Manufacturing: The process of redesigning of separate work areas/workstations into one integrated work area purposed to produce a finished product or product family.
- Yamazumi Boards: The boards that facilitate improved flow by displaying the time taken to complete activities and processes.
- Single Minute Exchange of Die: The technique that is used to minimise process changeover time.
- Jidoka: The production of zero-defect products through built-in quality.
- Taguchi Loss Function: The determination of the probability of customer satisfaction based on product specifications.
- Poka-Yoke: The design or configuration of processes to allow for easy detection of errors.
- Autonomation: The implementation of an automated process that relies on human involvement.
- Hoshin Kanri – Policy Deployment: The alignment of production processes to organisational objectives and business strategies.
- Key Performance Indicators: The metrics used to monitor and evaluate performance.
- SMART Goals: The design of Specific, Measurable, Achievable, Relevant and Time-bound goals.
- A3 Problem Solving: The iterative problem-solving method that involves the application of PDCA.

Value and Waste:

The Lean tools and techniques are implemented to minimise waste and maximise value. The Lean theory defines waste as a non-value adding activity and Toyota theory identifies waste as all elements which prevent an entity from achieving a perfectly efficient system (Pieńkowski, 2014; Teeuwen, 2011). A non-value adding activity is "anything other than the minimum amount of equipment, materials, parts, resources and time absolutely essential to production" (Hay, 1998 as cited by Barker & Naim, 2004). The essential ideas behind Lean (and Toyota theory) are exemplified by the 3Ms (Muda, Muri, Mura). The 3M's are interconnected and are utilised to group waste into three broad categories: Muda (waste), Muri (overburden) and Mura (unevenness) (Dierickx, 2016). Furthermore, Muda (waste) can be classified into eight types: overproduction, waiting, transport, over-processing, inventory, unnecessary motion, defects and insufficient use of human resources (Teeuwen, 2011; Thürer et al., 2017).

Value is defined as "the capability provided to the customer at the right time, at an appropriate price, as defined in each case by the customer" (Womack & Jones, 2003). Waste and value are closely related, and it has been proposed that defining value is a pre-requisite for defining waste (Kropsu-Vehkapera & Isoherranen, 2018; Fernandez-Solis & Rybkowski, 2012). The relationship between value and waste (non-value adding activities) has led to the classification of three types of activities within Lean, the three classes are (Womack & Jones, 2003):

- Value-adding activities
- Necessary and non-value adding activities (also known as support activities)
- Unnecessary and non-value adding activities

The Lean Enterprise Research Center at Cardiff Business School proposed that most production operations are composed of these three types of activities. Additionally, the research centre suggested that the activities often exist in the following proportions (Sharma et al., 2014):

- 5% value-adding activities
- 35% necessary and non-value adding activities
- 65% unnecessary and non-value adding activities

In summary, the 5 Lean principles illustrate the systematic characteristic of the Lean approach. The Lean approach consists of a variety of tools and techniques which are applied to increase value and minimise waste. Unpacking the Lean definition reveals that Lean methodology has distinct jargon, principles and practices.

2.1.2. Individual Methodology II: Value Engineering

The International Society of American Value Engineers (SAVE International) defines Value Engineering as follows:

> A systematic application of recognised techniques which identify the function of the product or service, establish a monetary value for that function and provide the necessary function at the lowest overall cost (VM Services, 2017, p. 38).

It is important to note that Value Engineering is often viewed as a subset of Value Methodology. Value Methodology is a combination of Value Management, Value Engineering and Value Analysis (VM Services, 2017, p. 44). Value Management (VM) is a strategic approach. Value Engineering (VE) is a tactical approach. Value Analysis (VA) is a technical approach. However, for the purposes of this research, the Value Engineering term is used to represent Value Methodology. This is because VM, VE and VA are all implemented using the same principles, tools and techniques, and their differences are purely based on the context in which they are applied (Prahladaraj, 2004).

Unpacking the Value Engineering definition

Similar to the Lean definition, the VE definition contains several concepts. These concepts can be grouped into two types: "systematic approach, tools & techniques" and "value & functions". These two concept groups are used to unpack the VE definition.

Systematic Approach, Tools and Techniques:

Within VE, the systematic application of recognised techniques is achieved through the execution of the VE Job Plan. The Job Plan consists of various phases, the description of these phases, as well as the associated tools, are summarised in Table 1 (Nassey, 2004; VM Services, 2017):

Table 1: The VE Job Plan and associated tools

Job Plan Phase Name	Job Plan Phase description	Tools
Information Phase	The activities conducted during this phase include scope definition, resource selection, objective setting and information gathering.	The tools used during this phase include Pareto principle, SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, scope definition, design to cost target and the objective matrix.
Function Phase	The functional requirements are defined during this phase, the functional	The tools and techniques used during this phase are Function Definition, Numerical

	relationships are analysed and the functions are prioritised.	Evaluation, Function Analysis System Technique (FAST) diagram, Redundancy Analysis and Function/Cost Analysis.
Innovation and Creativity Phase	Innovative and creative methods are applied to identify all possible solutions and alternative ideas that are best suited to functional requirements.	This process involves brainstorming and lateral thinking techniques.
Evaluation Phase	The proposed solutions and alternative ideas are evaluated and prioritised. The prioritised solutions and ideas are then selected for further investigation.	The tools applied include Concept Repertoire, Star Grading, Perspective Modelling, PIN (Positive, Interesting and Negative) analysis and SWOT analysis.
Investigation Phase	The prioritised solutions and alternative ideas are assessed based on feasibility, risk and financial requirements.	The tools include feasibility studies, risk assessments and various cost analysis methods.
Recommendation Phase	All studied and analysed information is consolidated; various reports (Study, Workshop and Management reports) are compiled and shared.	The applied techniques are action programmes, status audits and cost-benefit analysis.
Implementation Phase	The implementation activities are coordinated, responsibilities are assigned and action monitoring measures are implemented.	Audit and implementation techniques are applied.

Table 1 contains a summary of a 7-phase VE Job Plan. However, different authors summarise and consolidate the VE Job Plan phases in various ways (Ali & Assaf, 2005). Examples of variations are shown in Table 2.

Table 2: The various VE Job Plans

Three-Phase Job Plan (Ekanayake & Sandanayake, 2017)	**Five-Phase Job Plan Plan** (Ho et al., 2000; Odedairo & Bell, 2010; Shekari & Fallahian, 2007)	**Six-Phase Job Plan** (Lee et al., 2016; Nassey, 2004)	**Eight-Phase Job Plan** (Kheradia, 2011)
Pre-Study Phase	Pre-Study/ Information Phase		Preparation Phase
Value Study Phase: Information Sub-Phase		Information Gathering Phase	Information Phase
Value Study Phase:	Analysis Phase	Function Analysis Phase	Analysis Phase

Function Analysis Sub-Phase			
Value Study Phase: Creative Sub-Phase	Creative Phase	Speculative/ Creative Phase	Creative Phase
Value Study Phase: Evaluation Sub-Phase	Evaluation Phase	Evaluation Phase	Evaluation Phase
Value Study Phase: Development Sub-Phase		Development Phase	Development Phase
Value Study Phase: Presentation Sub-Phase	Presentation/ Implementation Phase	Presentation Phase	Presentation Phase
Post Study Phase			Follow-up Phase

The differences in the number of phases do not take away from the practices. All context-relevant tools and techniques are applied, although they may belong to phases that have different names.

Value and Functions:

The VE Job Plan is implemented to achieve the following objectives (as outlined in the VE definition):

- Identification of functions
- Establishment of value
- Provision of necessary function at the lowest overall cost

VE theory has measurable definitions for value and cost to facilitate the achievement of these three objectives. Value is expressed as a ratio of Function and Cost (VM Services, 2017).

$$Value = \frac{Function}{Cost}$$

The potential improvement to be made to a particular product/service/process can be determined using a Value Index that is expressed as follows (Nassey, 2004):

$$VI = \frac{FC}{FW}$$

Where VI is the Value Index, FC is the Function Cost (the cost incurred for a required/performed function) and FW is the Function Worth (the minimum cost that can be incurred in order to perform the required function). The higher the Value Index the greater the opportunity for improvement.

A function is a two-word (verb and noun) expression that encapsulates the purpose of a particular product/service/process. There are different types of functions. These types are listed below (Manea, 2017; VM Services, 2017):

- Work Functions: These are expressed using active verbs and measurable nouns (e.g. the function of a globe is to "produce light"). These functions are used to describe Use Value.
- Sell Functions: These are expressed using passive verbs and non-measurable nouns (e.g. the function of a luxury car is to "maintain prestige"). They are purposed to describe Esteem Value.
- Basic Functions: These are used to capture the primary purpose of the service/product/process. These functions occupy the first level of importance.
- Secondary Functions: These are used to describe the purposes that support the primary function. These functions occupy the second level of importance.
- Necessary Functions: These are those that contribute to Use Value.
- Unnecessary Functions: These are those that do not contribute to Use Value.

In summary, the VE approach comprises of a variety of tools and techniques which are utilised to increase value. However, unpacking the VE definition reveals that VE jargon, principles and practices are different from Lean jargon, principles and practices. Value Engineering is applied to maximise value from the functional perspective and Lean is applied to maximise value from the waste perspective. Both Lean and VE have a macro scale objective to maximise value. However, the methodologies encompass very distinct definitions, philosophies, approaches, tools and techniques. It is this existence of similarities and differences that academics and practitioners use to justify the development of Lean and VE hybrid methodology.

2.2. Lean and VE Hybrid Methodology

The first aim of this section is to expand on the hybrid development process (depicted in Figure 1) by following a literature synthesis process similar to that followed in the Kropsu-Vehkapera & Isoherranen (2018) study. Kropsu-Vehkapera & Isoherranen (2018) conducted their literature analysis in two stages: the first stage involved a review of literature and the second stage involved presentation of review-based *conclusions*. The second aim of this section is to explore the theoretical foundation of Lean and VE hybrid methodology (Cell & Arratia, 2003; Nayak, 2006; Shekari & Fallahian, 2007; Mandelbaum et al., 2010; Musa et al., 2016; Ekanayake & Sandanayake, 2017).

Literature shows that hybrid methodologies are often formed to overcome the weaknesses of individual CI methodologies (Bhuiyan & Baghel, 2005). Hybrid methodology development can also be justified by the need to merge the strengths of individual methodologies for the realisation of enhanced benefits (Singh & Singh, 2015; Nayak, 2006; Cell & Arratia, 2003).

The authors of Lean and VE hybrid methodology literature argue that this hybrid methodology can be utilised to achieve the following objectives:

- Realise the synergistic benefits of combined strengths (Cell & Arratia, 2003; Nayak, 2006; Mandelbaum et al., 2010)
- Expand the scope and view of the CI initiatives (Odedairo & Bell, 2010; Salvatierra-Garrido, 2011)
- Achieve a balance between value maximisation and waste elimination objectives (Sacadura & Tenera, 2011)
- Close the gaps that exist within individual methodologies (Sacadura & Tenera, 2011)
- Cope with the changes introduced by the fourth industrial revolution (Ozkeser, 2018)
- Develop competitive advantage (Borgianni et al., 2010; Ho et al., 2000; Kheradia, 2011; Nassey, 2004; Nayak, 2006; Shekari & Fallahian, 2011). This is the most common objective within the reviewed literature.

The authors formulate their theories by first examining the strengths, weaknesses, similarities and differences of Lean and VE.

Conclusion 1: Lean and VE hybrid methodology is developed to achieve specific objectives. Additionally, the initial steps of the development process involve a comparative analysis of Lean and VE to determine strengths, weaknesses, similarities and differences.

2.2.1. Lean and VE Similarities and Differences

Origins:

At first glance, Lean and VE might appear to be completely similar (Nayak, 2006; Musa et al., 2016); but the difference between them is evident in their origins. Lean (Toyota Production System) was pioneered by Toyota's Taiichi Ohno just after World War II to simultaneously achieve variety in products and continuity in process flow (Lean Enterprise Institute, 2000). General Electric's Lawrence D. Miles is the father of VE, material shortages forced him to specify components based on function for substitutional material procurement purposes, and the specification resulted in finished products that provided the required function at a lower cost (Lane Davis, 2004). It is clear from the brief histories that the origins of Lean and VE were based on different intentions; the intention of Lean was to achieve variety and improve production line flow while the intention of VE was to identify substitute materials (Nayak, 2006). The origins suggest that the Lean and VE approach can vary in terms of intent.

Definitions:

Another distinguishing factor for these two CI methodologies resides in their definitions (detailed in section 2.1). These definitions expose a difference in focus: Lean efforts are directed at waste

elimination and VE efforts focus on function provision at the lowest overall cost. Additionally, the definitions imply differences in jargon, logic and mechanics.

Approach, Objectives, Concepts & Tools:

Conversely, Lean and VE definitions reveal that there are similarities between the two methodologies. Both methodologies offer a *systematic approach to achieve improvements* and they can both be used to achieve similar high-level objectives (Nayak, 2006). Although it can be argued that an objective such as "apply a systematic approach to achieve improvements" is imprecise and more detailed objectives such as Lean's "achieve variety in products and process flow" and VE's "procurement of substitutional material" show that Lean and VE can also be used to achieve varying low-level objectives. The high-level objectives of Lean and VE can be similar while the microscale objectives differ. Furthermore, there are factors in the concepts and mechanics of Lean and VE that provide evidence of similarities in approach. Both methods can increase customer value and both employ visual analysis tools through a team approach (Nayak, 2006; Musa et al., 2016). Lean and VE can both be used to increase value but they have different definitions of value, Lean associates value with a customer's willingness to pay (Teeuwen, 2011), and VE defines value as a ratio between function and cost (VM Services, 2017). This is another example of macro-scale similarities that are associated with micro-scale differences: the high-level Lean approach to increase value is similar to the VE approach, however, the differences in value definitions indicate that the micro-scale Lean approach to increase value is not exactly the same the VE approach. The two methodologies both offer tools for visual analysis, but VE's Function Analysis System Technique (FAST tool) is based on function and Lean's Value Stream Mapping (VSM tool) is based on waste. Yet again, this is another example of Lean and VE having similar macro-scale approaches to "apply visual analytical tools" but the differences in the tool features reveal differences in approach when this factor is viewed with a micro lens. And thus, the examined Lean and VE factors (definition, objectives, approach, customer value and visual analysis tools) demonstrate that what is defined as a similarity using a macro scale frame can be re-defined as a difference when viewed with a micro lens. Nayak (2006) and Musa et al. (2016) agree by saying that Lean and VE can seem similar at a high level but an interrogation of the details can reveal differences.

Conclusion 2: One of the most important factors when determining Lean and VE similarities and differences is scale. This is because some macro-scale similarities between Lean and VE are associated with micro-scale differences.

2.2.2. Lean and VE Strengths and Weaknesses

Literature shows that there is a general agreement among authors regarding the assessment of Lean and VE similarities and differences. However, this does not hold true for the comparative analysis process that is purposed to produce Lean and VE strengths and weaknesses.

Nayak (2006) conducted a comparative analysis of Lean and VE strengths and weaknesses. He put forward that Lean strengths are value creation and team concept. His proposal did not include one of the other notable strengths of Lean, which is that it is a collection of principles and practices that influence culture and provide tools for iterative and ongoing implementation, as highlighted by Cell & Arratia (2003). The Nayak (2006) study contains a view that Lean's weakness is a lack of analytical tools. Nayak (2006) does not acknowledge the identification of the 8 types of waste as an analytical technique, but Cell & Arratia (2003) do. Cell & Arratia (2003) propose that waste classification is an analytical tool that can add to the VE function analysis process. Moreover, they observe that Lean has an "analytical lexicon" that includes spaghetti diagrams, flow diagrams, bar charts and control boards.

Furthermore, Nayak (2006) proposes that VE's strength is found in the value equation, team orientation and applicability to low data stages (design and feasibility stages). However, Mandelbaum et al. (2010) differ by suggesting that function analysis, the FAST diagram and cost focus are the strengths of VE. Cell & Arratia (2003) differ too in their assessment of VE strengths, they propose that VE offers highly effective ways to prioritise problem areas and it allows for maximised cost saving in the least time. These examples show that there is notable variation in the classification of strengths and weaknesses. This may be due to the fact that a comparative analysis that is purposed to determine strengths and weaknesses is subjective and influenced by context. This could explain why Nayak (2006) recommends that practitioners must consider the advantages and disadvantages of individual application of Lean and VE within the contexts of their own organisation's products, processes and system objectives when developing a Lean and VE hybrid methodology strategy.

Conclusion 3: The assessment of Lean and VE the strengths and weaknesses can be subjective and context dependent. And thus, a comparative analysis process which is purposed to determine strengths and weaknesses must include a consideration of organisational characteristics. This analysis step can yield strengths and weaknesses or advantages and disadvantages of Lean and VE within the organisational context.

2.2.3. Lean and VE Comparative Analysis Factors

Sections 2.2.1 and 2.2.2 contain a brief examination of Lean and VE similarities, differences, strengths and weaknesses. The similarities, differences, strengths and weaknesses are analysed using the following factors:

- Origin
- Definition
- Objectives
- Approach
- Customer value
- Visual analysis tools
- Tools and techniques
- Scope
- Focus

These factors are utilised to conduct a qualitative comparison (see Sections 2.2.1 and 2.2.2), as is often done when two CI methodologies are examined (Ali & Assaf, 2005). Ali & Assaf (2005) conducted a qualitative comparison of CI techniques using four factors: training, number of required personnel, implementation time and implementation cost. Practitioners often distinguish their methodologies from others using factors such as origin, vocabulary, training, effectiveness and applicability (Mandelbaum et al., 2010). Lean and VE hybrid methodology researchers use several comparative analysis factors to study similarities (Musa et al., 2016; Cell & Arratia, 2003), differences (Musa et al., 2016), similarities & differences (Shekari & Fallahian, 2007; Ekanayake & Sandanayake, 2017; Nayak, 2006) and strengths & weaknesses (Cell & Arratia, 2003; Nayak, 2006). Examples of these comparative analysis factors include:

- Objective
- Origin
- Techniques
- Approach
- Usage/application
- Scope
- Customer focus
- Research
- Project Life Cycle implementation stage
- Visual analytical tools
- Team dynamics
- Cost
- Quality

- Key Performance Indicators
- Management involvement
- Potential savings implementation timeframe
- Benefits
- Application area
- Key success factors
- Value concept
- Limitations
- Initial results
- Theory
- Hypothesis
- Project selection criteria

Conclusion 4: The similarities, differences, strengths, weaknesses, advantages and disadvantages of Lean and VE can be explored using a variety of Comparative Analysis Factors (CAF).

CAF can be employed to compare the *theory* (principles and concepts) and the *practices* (tools and techniques) of Lean and VE. The CAF described above were used to compare Lean and VE theory based on principles/concepts (e.g. value concept and customer focus), and they were utilised to compare Lean and VE practices based on tools/techniques (e.g. visual analytical tools, team dynamics and approach). Additionally, the comparison of Lean and VE *practices* can be based on *activities*. For instance, Nayak (2006) outlined the similarities between the Lean VSM activities and the VE Job Plan activities (illustrated in Table 3). Similarly, Shekari & Fallahian (2007) compared Lean and VE practices based on an analysis of activities, however, their analysis was purposed to identify opportunities where VE activities can be added to the Lean process. Other authors have compared Lean and VE activities using the 5 Lean principles and The VE Job Plan (Ekanayake & Sandanayake, 2017). Notably, there are limitations associated with comparing CI methodology activities. Mandelbaum et al. (2010) highlighted that the differences in the theoretical and the empirical limit the ability to conduct an accurate theoretical activity-based comparative analyses.

Conclusion 5: The comparative analysis of Lean and VE *theory* and *practices* can be based on Principles/Concepts and Activities/Tools/Techniques.

Table 3: Similarities between Lean VSM elements and the VE Job Plan

Lean Manufacturing Elements	Value Management Job Plan	Purpose
Current State Map (CSM)	Information Phase / Functional Phase	a. Define problem to be solved, gather background material and data, establish system/process functions/characteristics. b. Identify inputs/outputs and relationship, identify sources of defects/cost drivers
Future State Map (FSM)	Speculation Phase / (Creative Phase) Evaluation Phase	a. Screen potential opportunity areas, Evaluate alternative opportunities
Future State Map (FSM)	Development Phase	a. Identify optimal designs/operating conditions from alternative opportunities
Implementation Plan	Implementation Phase	a. Implement process/design improvements, validate and document results

It is apparent that the Lean and VE comparative analysis process is complex. Authors of Lean and VE hybrid methodology literature generally show agreement in their assessment of similarities and differences. However, there is some variation in the comparative analysis of strengths and weaknesses. Moreover, Lean and VE similarities can be a function of scale, some Lean and VE elements are similar at a high-level but different when viewed using a micro lens. Strengths and weaknesses can be context-dependent and therefore require consideration of organisational characteristics. The variances do not take away from the benefits of this hybrid methodology, instead, they indicate complexity and therefore a need to apply expansive and exhaustive methods to develop implementation strategies (Finfgeld-Connett & Johnson, 2013). The implementation strategies that are recommended for Lean and VE hybrid methodology often involve models. For the purposes of this study, these models have been separated into three types: Interchangeable Use (Nayak, 2006; Musa et al., 2016); Concurrent Use and Integrated Use models (Nayak, 2006; Cell & Arratia, 2003; Ekanayake & Sandanayake, 2017; Mandelbaum et al., 2010).

2.3. Lean and VE Hybrid Methodology Models

The authors of Lean and VE hybrid methodology literature explore the theoretical basis for this methodology and provide strategies for implementation. These strategies are presented as models. For the purposes of this study, these models are categorised into three types:

- Interchangeable Use models: the employment of either Lean or VE (or their components) in a substitutional manner. Lean and VE are applied separately and are mutually exclusive. (Nayak, 2006; Musa et al., 2016)
- Concurrent Use models: the simultaneous application of individual Lean and VE (or their components). Lean and VE are applied separately and are mutually inclusive. (Cell & Arratia, 2003; Nayak, 2006)

- Integrated Use models: the sequenced implementation of amalgamated Lean and VE (or their combined components). Lean and VE connected, interdependent and form a coherent whole. Lean and VE are applied together through a merged structure. (Nayak, 2006; Cell & Arratia, 2003; Ekanayake & Sandanayake, 2017; Mandelbaum et al., 2010)

Implementation strategies can also include hybrids of two or more of these model types (e.g. a model that is a combination of Interchangeable and Integrated Use (Borgianni et al., 2010)). However, these model forms are beyond the scope of this study. The purpose of this section is to discuss the three Lean and VE hybrid methodology model types.

2.3.1. Interchangeable Use Models

Lean and VE are both CI methodologies yet they differ significantly in terms of scope. VE is a robust analytical methodology that is often used to episodically improve specific projects or areas within organisations and Lean is a collection of principles, practices and techniques which are implemented to improve specific projects and areas and are applied to continuously influence organisational culture (Cell & Arratia, 2003). Moreover, it has been established that Lean and VE have notable differences in terms of logic, mechanics and concepts. Due to these differences, Lean and VE (in their entirety) are not interchangeable (Nayak, 2006; Musa et al, 2016). However, Lean and VE do have similarities. They both have highly effective visual analytical tools, workforce participation strategies, customer-focused strategies and value increasing and cost-reducing techniques (Nayak, 2006). The existence of similarities is a requirement for Interchangeable Use (Nayak, 2006; Musa et al., 2016), and since similarities do exist, Lean and VE hybrid methodology can be applied through Interchangeable Use models. These models must be created with caution because similarities are a function of scale. Nayak (2006) states that an assessment of organisational processes and objectives can be used to design Lean and VE hybrid systems. For example, an organisation that aims to reduce costs through the application of visual analytical tools and workforce participation can use these objectives to justify Interchangeable Use. Nayak (2006) shows both Lean and VE to be equally highly effective in these areas. Additionally, Cell & Arratia (2003) and Nayak (2006) propose that Lean and VE do not need to be linked or symbiotic for hybrid methodology benefits to be realised. The most effective tools can be applied based on their suitability to organisational conditions. The required organisational conditions for Lean and VE success differ (Cell & Arratia, 2003), and Lean and VE similarities (customer focus, value increase, cost reduction, workforce participation, systematic approach) can allow for the same objectives to be met in varying organisational circumstances through the application of Interchangeable Use models.

2.3.2. Concurrent Use Models

Similar to Interchangeable Use, Concurrent Use is another model type that allows for the benefits of Lean and VE hybrid methodology to be realised without creating a linked and co-dependent Lean and VE relationship (Cell & Arratia, 2003; Nayak, 2006). This model allows for separate and simultaneous application of Lean and VE in the same area and it also allows for the parallel application of Lean and VE by different practitioners in different areas. This type of Lean and VE hybrid methodology implementation method enables an extensive range of CI requirements to be met simultaneously without linking Lean and VE activities (Nayak, 2006). For instance, the application of Lean can be most suitable to areas that require culture transformation, and the application of VE can be most suitable to problems that require an analytical tool (Cell & Arratia, 2003), and thus Concurrent Use can be implemented to address organisational culture and to create analytical solutions by leveraging this difference (Cell & Arratia, 2003; Nayak, 2006). The application of VE methodology to design, feasibility and material selection can benefit the Initiation and Planning phases of the Project Life Cycle (VM Services, 2017), and Lean Flow Analysis (Do, 2017) can be applied to the same phases of Project Life Cycle. Yet again, this is another example of Concurrent Use applicability, this time within project management.

2.3.3. Integrated Use Models

Unlike the first two model types, Integrated Use models feature Lean and VE in a linked and co-dependent form. This model involves the merging of Lean and VE in a complementary manner, where either the one methodology is used to strengthen the another (Shekari & Fallahian, 2007) or two strengths are combined which results in synergy (Cell & Arratia, 2003; Nayak, 2006). When it comes to Integrated Use, Mandelbaum et al. (2010) propose that the opportunity to benefit from hybrid methodology over a Life Cycle varies depending on whether the application is for a product, service or construction project. An example of one Integrated Use model proposal consists of the following steps (Nayak, 2006): 1) Opportunity selection that is tied to an organisations goals, and 2) Implementation of enterprise-level Value Stream Mapping (Current State and Future State, where Future State establishment includes action targeting based on VE methods). Another example features the addition of VE in a factory floor Kaizen event, where VE function analysis is incorporated into the Create Lean Cell step (Cell & Arratia, 2003). Shekari & Fallahian (2007) propose an Integrated Use model that not only relies on the suitable merging of the two methodologies but also requires appropriate sequencing of the methodologies.

Overall, the differences between the three model types are related to when and how Lean and VE are applied. The definitions indicate whether Lean and VE are applied at the same time (Concurrent Use), one after the other (Interchangeable Use) or as steps that form part of a structured sequence (Integrated

Use). Additionally, the definitions indicate whether Lean and VE are applied separately (Interchangeable or Concurrent Use) or in a merged form (Integrated Use).

Conclusion 6: Lean and VE hybrid methodology can be implemented using three types of models, namely Interchangeable Use, Concurrent Use and Integrated Use models.

In summary, the Lean and VE hybrid methodology development is a complex process. The literature review revealed 6 main conclusions regarding these complexities:

- **Conclusion 1**: Lean and VE hybrid methodology is developed to achieve specific objectives. Additionally, the initial steps of the development process involve a comparative analysis of Lean and VE to determine strengths, weaknesses, similarities and differences.
- **Conclusion 2**: One of the most important factors when determining Lean and VE similarities and differences is scale. This is because some macro-scale similarities between Lean and VE are associated with micro-scale differences.
- **Conclusion 3**: The assessment of Lean and VE the strengths and weaknesses can be subjective and context dependent. And thus, a comparative analysis process which is purposed to determine strengths and weaknesses must include a consideration of organisational characteristics. This analysis step can yield strengths and weaknesses or advantages and disadvantages of Lean and VE within the organisational context.
- **Conclusion 4**: The similarities, differences, strengths, weaknesses, advantages and disadvantages of Lean and VE can be explored using a variety of Comparative Analysis Factors (CAF).
- **Conclusion 5**: The comparative analysis of Lean and VE *theory* and *practices* can be based on Principles/Concepts and Activities/Tools/Techniques.
- **Conclusion 6:** Lean and VE hybrid methodology can be implemented using three types of models, namely Interchangeable Use, Concurrent Use and Integrated Use models.

The conclusions were integrated with the steps that are outlined in Figure 1 to form the expanded Lean and VE hybrid methodology development process, illustrated by Figure 3. This expanded depiction of the development process is similar to the process followed in the Nayak (2006) study, the steps are as follows:

- The examination of Lean and VE theory and practices.
- The comparative analysis of Lean and VE to determine strengths and weaknesses or advantages and disadvantages. This analysis is based on organisational factors (products, processes and system objectives).
- The comparative analysis of Lean and VE to determine similarities and differences.

- The completion of a decision process. This decision process is a missing “Model Selection Framework” that this study aims to establish.
- The implementation of Lean and VE hybrid methodology using the selected model type.

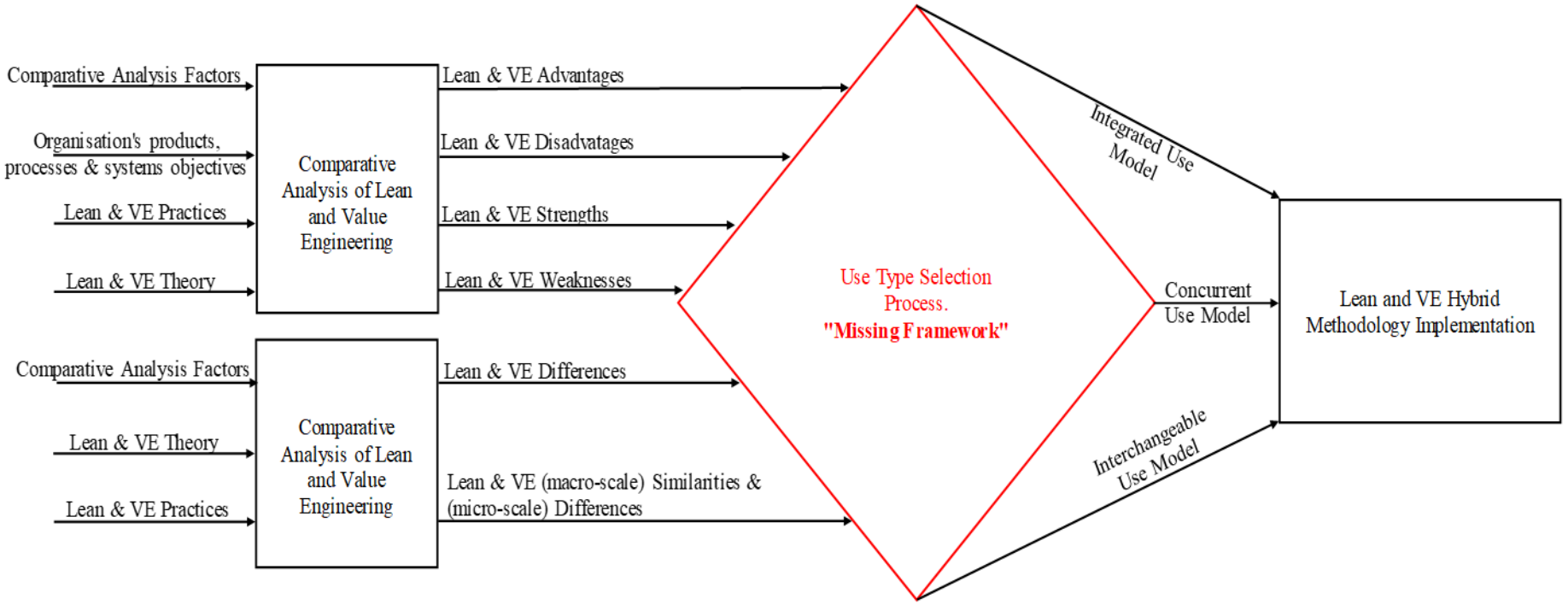


Figure 3: Proposed Lean and VE Hybrid methodology Development Process (expanded)

The process outlined in Figure 3 is the theoretical framework on which this study is based.

2.3.4. Implementation Barriers and Facilitators

Lean and VE have similarities, differences, strengths and weaknesses that can be leveraged in a manner that allows for the realisation of hybrid methodology benefits. However, it is important to note that Lean and VE were designed separately, with no intention for them to be matched (Nayak, 2006). This creates barriers or facilitators for the Lean and VE merging process.

Nayak (2006) briefly highlights possible barriers by noting that there are difficulties in successfully implementing one method within an organisation, and these difficulties could be amplified when aiming to successfully implement the combined methodologies. He proposes that a possible solution is to manage the process using the appropriate experience, skills, judgement and determination. Similarly, Kheradia (2011) highlights the potential difficulties that could arise in Lean and VE integration. He notes that a combined Lean and VE investigation could result in oversimplification or hyper-analysis of the process/product being investigated. This oversimplification and hyper-analysis could lead to an outcome where the efforts which are purposed to eliminate waste result in the introduction of more waste. The risk of introducing waste into a system through Lean and VE integration is a potential barrier. Furthermore, other authors have highlighted potential barriers to be lack of industry readiness, attitudes and behaviours, lack of knowledge, implementation cost and time, lack of technology and lack of management commitment (Ekanayake & Sandanayake, 2017).

Lean and VE, as individual CI methodologies, have key success factors. The key success factors for Lean implementation are management commitment, team approach, adequate training on the Lean principles, a culture that enables the right ingredients (waste identification, growth and change) and the appointment of Lean leadership personnel (a Lean Sensei) (Ekanayake & Sandanayake, 2017; Nayak, 2006). The key success factors for VE implementation are the appointment of a Certified Value Specialist, management involvement, team training, an experienced multi-disciplinary team and effective communication (Ekanayake & Sandanayake, 2017; Nayak, 2006). Some Lean and VE key success factors are similar (e.g. the need for management commitment, team approach) and similarities make Lean and VE complementary and thus facilitating hybrid methodology implementation (Parker, 2015). However, some Lean and VE key success factors are different. Lean training is required for the entire organisation and can be extensive, whereas VE training is required for the VE project team members only (Ali & Assaf, 2005). The differences in training requirements could cause compromise and conflict of objectives, and this could introduce implementation barriers.

On the other hand, Cell & Arratia (2003) simply state that the existence of Lean and VE conflict is unfounded, and they do not provide support for this claim. Additionally, Cell & Arratia (2003) claim that the appropriate sequencing of Lean and VE activities can facilitate hybrid methodology

implementation; they propose that the culture created by initial Lean implementation creates an environment that is suitable for subsequent VE implementation. Shekari & Fallahian (2007) agree that suitable sequencing of Lean and VE activities within a hybrid methodology strategy can facilitate success. It is important to note that the Lean implementation timeframe (long term and ongoing) is different from the VE implementation time frame (traditionally short term and episodic) (Nayak, 2006), this factor may need to be considered in the design of sequence-dependent strategies (Integrated Use models).

The reviewed studies did not explore how the differences in jargon could affect the ease of understanding, nor did they explore the type of training strategy that would be appropriate for Lean and VE hybrid methodology implementation. Nayak (2006) notes that Lean and VE have different entry costs and resource utilisation levels, this too has not been explored extensively. The resource (financial or human) requirements for Lean and VE integration could be a significant barrier.

In summary, literature (section 2.1 to 2.3) shows that Lean and VE similarities, differences, strengths and weaknesses are leveraged to develop Lean and VE hybrid methodology. This hybrid methodology can be implemented using three types of models. Hybrid methodology models are formed through the selection and grouping of the various Lean and VE components, and the selected components and grouping sequences can differ based on context. The application of these models is vulnerable to barriers, some of these potential barriers have been explored and some are yet to be explored. Nevertheless, Lean and VE hybrid methodology can provide benefits that exceed those provided by one methodology. Furthermore, Lean and VE have similar value maximisation objectives and this makes them complementary methods, this is an implementation facilitator. Another important facilitator of implementation is a guiding framework. However, literature does not provide a selection framework for the three model types (Interchangeable, Concurrent and Integrated Use) and this is the motivation for this study.

2.4. Frameworks in Lean and Value Engineering

A framework is an important factor in the successful implementation of individual Lean and VE methodologies (Haque & Chauhuri, 2015; VM Services, 2017), therefore it is equally important in the successful implementation of Lean and VE hybrid methodology. The simplest form of a Lean framework is: Define Customer Value, Map the Value Stream, Create Flow, Establish Pull and Pursue Perfection (Do, 2017). Likewise, the VE Job Plan consists of elements and steps organised into Pre-study, Information, Function Analysis, Creative, Evaluation, Development, Presentation and Post-study phases (VM Services, 2017), these phases can be regarded as a VE framework.

2.4.1. Hybrid Methodology Frameworks

It is not uncommon for an individual CI methodology framework to be augmented to suit the development of a hybrid CI methodology framework. For instance, in the implementation of Lean Six Sigma, the Lean framework is augmented to suit its combination with Six Sigma. This is illustrated by Figure 4, where the Six Sigma DMAIC (Define, Measure, Analyse, Improve, Control) phases feature Lean tools and techniques (e.g. Kaizen, Value Stream Mapping, Kanban) (Okoli, 2015; Chaurasia et al., 2016).

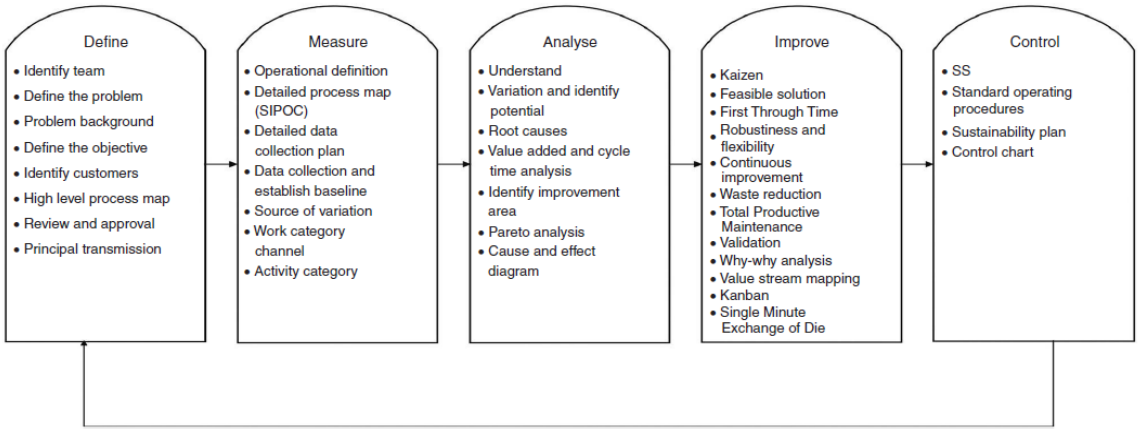


Figure 4: Lean Six Sigma Framework (Chaurasia et al., 2016)

Similarly, the implementation of Risk Management Integrated VE involves the augmentation of VE framework to suit its grouping with the Risk Assessment process, this is illustrated in Figure 5 (El Khatib, 2015). This hybrid framework features the incorporation of risk management activities into the VE Job Plan phases.

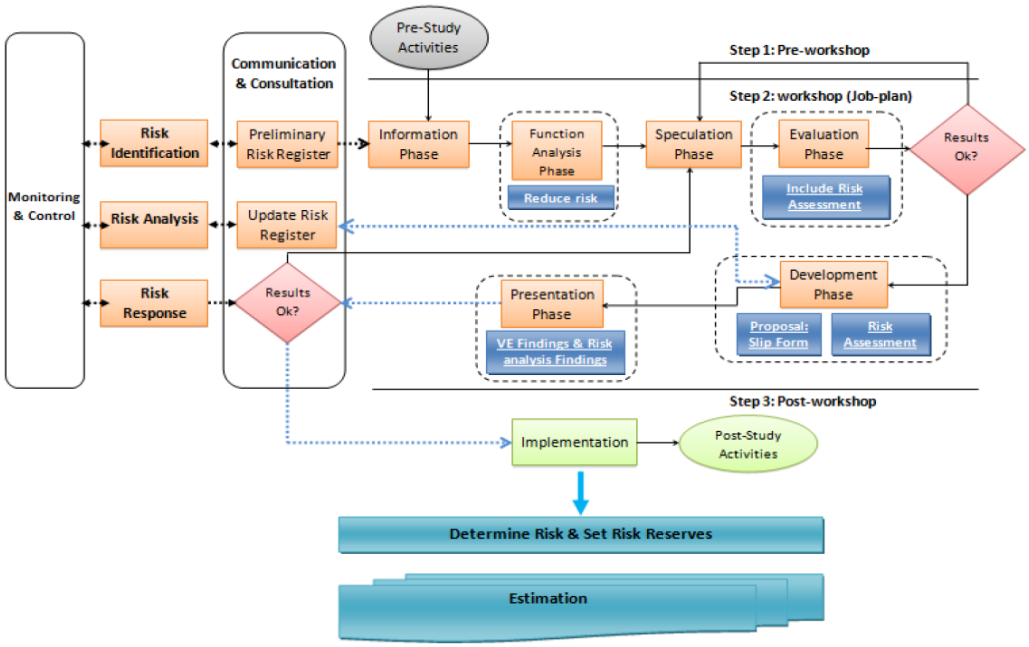


Figure 5: Risk Management Integrated VE Framework (El Khatib, 2015)

The Lean Six Sigma (Chaurasia et al., 2016) and Risk Management Integrated VE frameworks (El Khatib, 2015) show the integration of tools and activities, this is a common occurrence when two methodologies are combined. An example of this can be found in a study by Shekari & Fallahian (2007), this study proposes a Lean and VE hybrid methodology framework (presented as an algorithm). The algorithm involves a convergence of Lean and VE tools and activities. The framework considers the organisational context (objectives, scope, goals, training, financial conditions) and multi-stakeholder input (teams, managers, suppliers, customers). However, the framework mostly consists of Lean elements and only includes three VE elements namely, Creative (brainstorming), Prioritisation and Function Analysis. This framework is illustrated by Figure 6. This diagram illustrates an Integrated Use model where the following is observed:

- VE elements are amalgamated with Lean and form a sequenced structure
- Lean and VE are implemented in a merged form
- Lean and VE are connected and interdependent

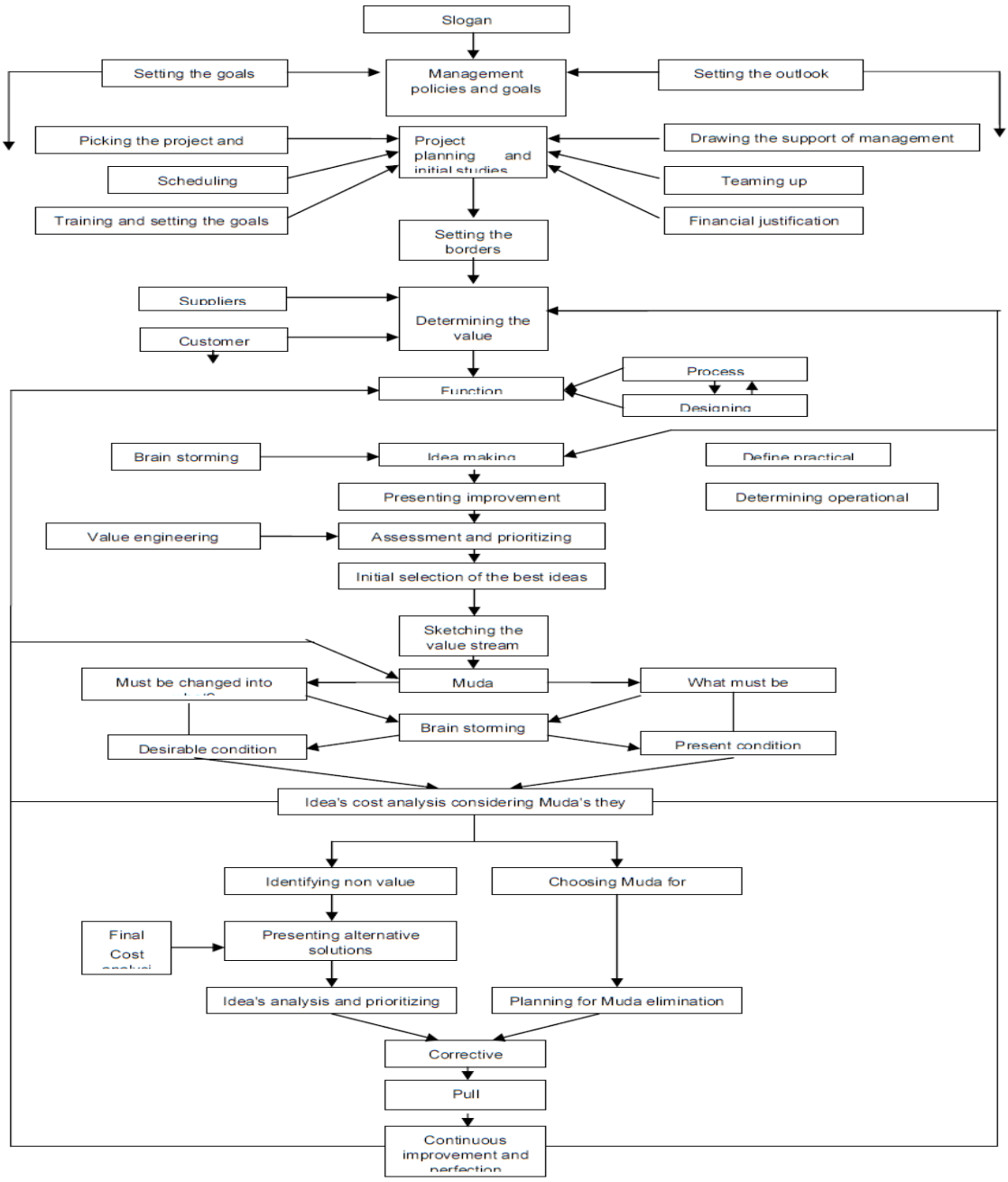


Figure 6: Lean and VE Framework: The LVE Algorithm (Shekari & Fallahian, 2007)

Notably, Lean and VE hybrid methodology does not only provide opportunities to combine Lean tools/activities with VE tools/activities, but it also provides the opportunity to merge principles/concepts. Nayak (2006) demonstrates this through his proposed Lean and VE framework (presented as Lean Value Management House and illustrated by Figure 7). This framework shows the convergence of Lean and VE tools, activities, focus areas, approaches, waste and value concepts. It is not an implementation model; it is a framework that illustrates the concepts of Lean and VE in a combined form.

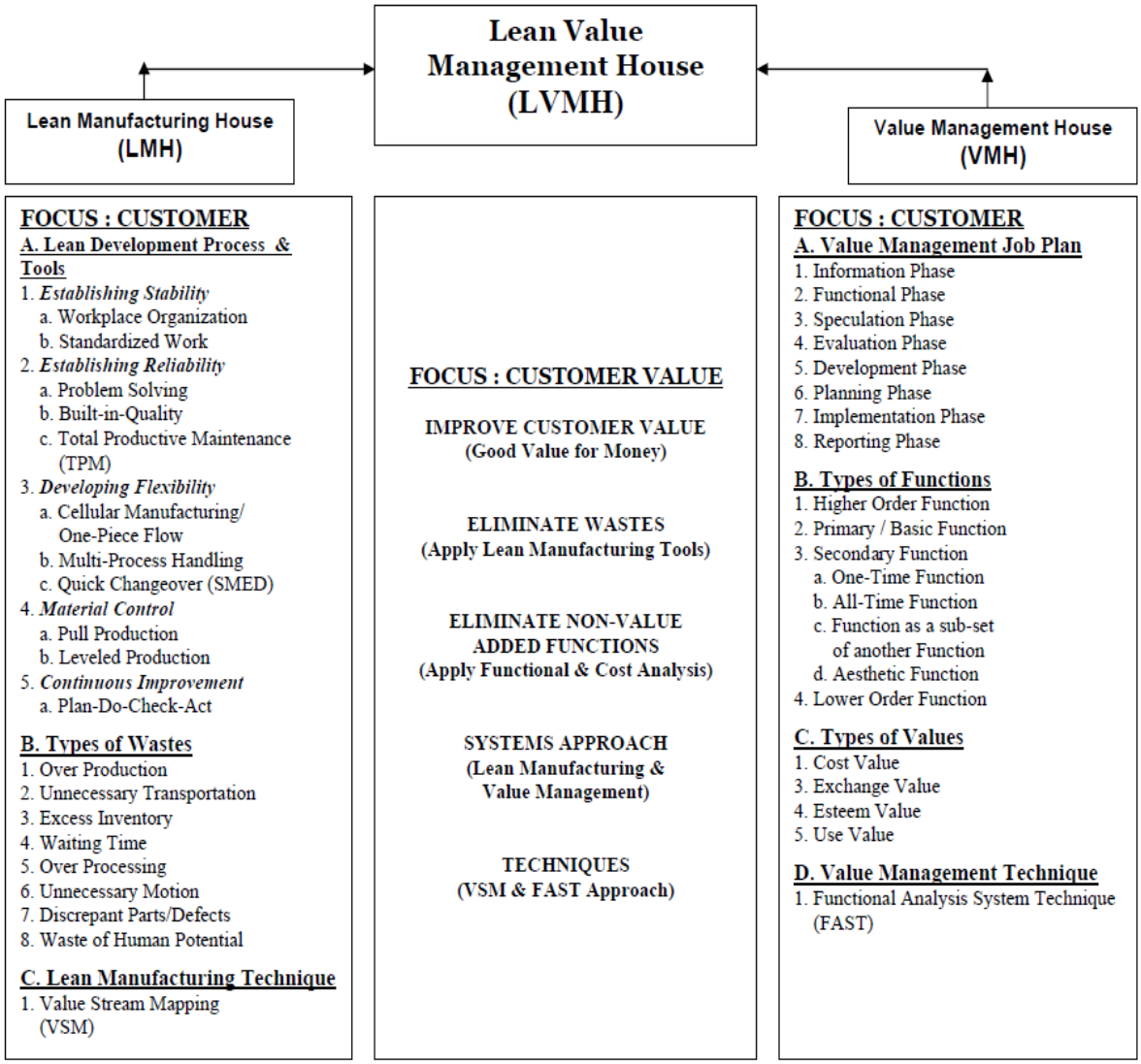


Figure 7: Lean and VE Framework: Lean Value Management House (Nayak, 2006)

In summary, a framework is an important factor in CI methodology implementation. Individual Lean and VE methodologies have principles and practices that can be classified as frameworks. Additionally, Lean and VE frameworks can be augmented to develop hybrid CI methodology frameworks. For instance, there are frameworks that guide the implementation of hybrid methodologies such as Lean Six Sigma, Risk Management Integrated VE and Lean and VE hybrid methodologies. Lean and VE hybrid methodology frameworks can also be used to guide model implementation and to illustrate the convergence of Lean and VE concepts. However, the purpose of this study is not to develop a framework that simply guides implementation or illustrates convergence, the purpose of this study is to develop a model selection/decision-making framework.

2.4.2. Decision-Making Methods and Frameworks

Lean and VE approaches both have tools and techniques that are designed to guide decision-making processes. The VE Job Plan is comprised of decision-making tools and techniques that are designed to guide teams during the Information Gathering, Function Analysis and Evaluation phases (VM Services, 2017). The Pareto principle can be applied to select priority areas during the Information Gathering phase, Numerical Evaluation can be applied to select priority functions during the Function Analysis phase, and Perspective Modelling and Positive/Negative/Interesting (PIN) analysis can be utilised to select the best alternative during the Evaluation phase (VM Services, 2017). Some researchers claim that the decision-making tools employed in the VE Evaluation phase are unsound because they rely on the abstract allocation of criteria rating, subjective pair-wise comparison, and advantages and disadvantages (Wao, 2015). Wao (2015) proposed the Choosing by Advantages (CBA) method for the VE Evaluation phase because this method is based on the importance of advantages only and the decisions are supported by relevant facts. CBA is a multi-stakeholder decision-making tool, it enables sound, transparent and auditable decision-making by comparing the advantages of alternatives (Kpamma et al., 2018). This method is considered to be a Multi-Criteria Decision Method (MCDM), researchers propose that it is superior to other well-known MDCMs such as Analytical Hierarchy Process (AHP) (Kpamma et al., 2018). CBA is an emergent (in research and practice) Lean Construction tool. The CBA decision-making method involves 6 steps (Kpamma et al., 2018):

- Listing of alternatives
- Identification of factors
- Description of attributes
- Establishment of advantages by comparing attributes
- Assigning importance to advantages
- Selection of the alternative with the greater advantages

Similar to VE, The Lean toolbox includes tools that guide decision-making processes. Root Cause Analysis, Pareto analysis and the Cause and Effect Diagram can be used to select priority areas and objectives (Chaurasia et al., 2016). Moreover, Lean has a large collection of tools and this creates a need for organisations to undergo decision-making processes to select context-suitable tools. For instance, Ramesh & Kodali (2012) conducted a study to establish a decision framework, this framework was purposed to not only guide the selection of appropriate Lean tools but to also assist with the selection of optimum tool implementation sequences. This proposed selection framework (illustrated in Figure 8) consists of the following steps (Ramesh & Kodali, 2012):

- Definition of organisational performance measures
- Identification of suitable Value Stream Mapping (VSM) tools

- Application of Analytical Hierarchy Process (AHP) to select the best VSM tool that utilises minimum time and effort based on current organisational priorities
- Identification and prioritisation of performance metrics for each Performance Measure (PM)
- Application of a Pre-emptive Goal Programming (PGP) process
    - Selection of VSM tools for future prioritisation
    - Identification of best tool application sequence
    - Identification of optimum value of performance metrics under a defined constraint
- Comparison of the optimum value of the metrics and real-time performance values in order to decide whether to continue using the selected use of the tool or implement the proceeding tools, as defined by the PGP sequence

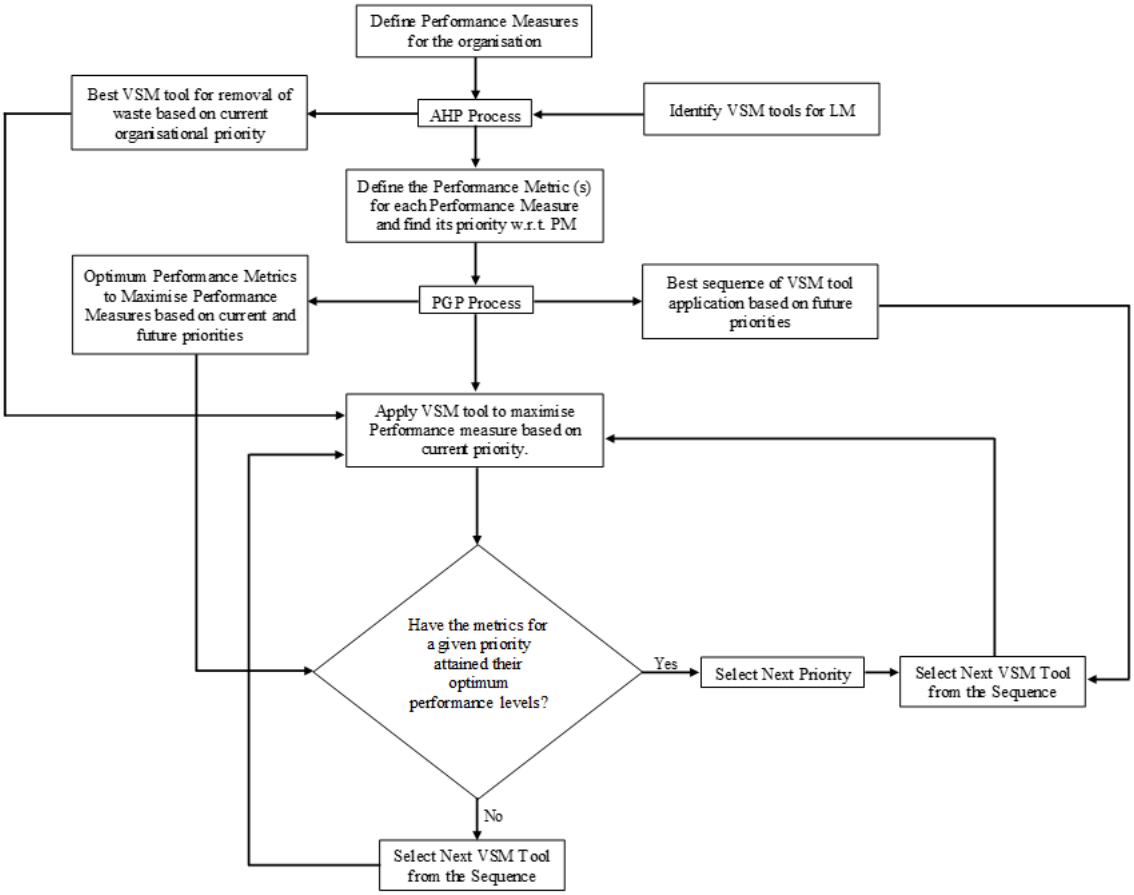


Figure 8: VSM Tool Selection Framework (Ramesh & Kodali, 2012)

The VSM tool decision-making framework that is illustrated by Figure 8 makes use of PGP and AHP, these methods form part of MCDM. MCDM is a method that involves quantitative and qualitative factors and makes use of computational and mathematical tools to guide the subjective evaluation of performance criteria (Mardani et al., 2015). MCDM approaches are separated into two types (Kahraman, 2008):

- Multi-Objective Decision Making (MODM) approaches
    - Used to design the best alternative

    - Considers trade-offs and constraints
    - The alternatives are infinite
    - Utilised for Selection Decisions
    - Selection Decisions are made using methods such as AHP, ANP, TOPIS (Technique for Order Preference by Similarity to Ideal Solution), PROMETHEE (Preference Ranking Organisation METHod for Enrichment of Evaluations) and Goal Programming
- Multi-Attribute Decision Making (MADM) approaches
    - Used to make selections within the confines of decision criteria
    - There are a limited number of alternatives
    - Utilised for Sorting and Ranking Decisions
    - Sorting and Ranking Decisions are made using methods such as AHP, MAUT, MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique), AHPSort (Analytical Hierarchy Process Sort), FlowSort

The MADM and MODM methods can be implemented using software packages, this ability is particularly important because the role that the fourth Industrial Revolution (4IR) plays in the current operational research context.

In summary, a decision-making framework is expected in Lean application because Lean is a collection of a number of principles, tools and techniques. Ramesh & Kodali (2012) developed the VSM tool selection framework to overcome the challenges associated with having a number of implementation options within Lean. On the other hand, VE is described as an analytical technique and is not characterised by a collection of principles, tools and techniques and therefore does not require a tool selection framework. Similar to the Ramesh & Kodali (2012) problem, Lean and VE hybrid methodology features several implementation options (Interchangeable Use, Concurrent Use and Integrated Use models). Similar to the Ramesh & Kodali (2012) objectives, this study aims to address those challenges by establishing a model selection framework. Current operational research trends show a movement to fact-based and 4IR suitable decision-making approaches like CBA, MADM and MODM. It is therefore important to ensure that the established framework aligns with these trends.

2.5. Chapter Summary

Literature shows that Lean and VE originated in the manufacturing industry, and both methodologies offer systematic approaches that can be utilised to increase value. This similarity can lead to the conclusion that the two methodologies are the same. However, a detailed review of their definitions shows that the methodologies have distinct jargon, principles and practices. It is the existence of similarities and differences that practitioners and scholars utilise to argue that Lean and VE can be

suitably merged to form Lean and VE hybrid methodology. They propose that the methodology can be utilised to achieve a number of objectives, the most common within the reviewed literature is competitive advantage. Other objectives include synergistic benefits, a balance between waste reduction and value increase and overcoming the weaknesses of one methodology.

Literature shows that the development of Lean and VE hybrid methodology consists of several steps. The first is an examination of Lean and VE theory and practices, the second is a comparative analysis of Lean and VE methodologies to determine similarities, differences, strengths and weaknesses, the third is a selection of implementation models (Interchangeable Use models, Concurrent Use models and Integrated Use models) and lastly, the fourth is the implementation of the models. Unfortunately, literature does not offer a model selection framework. This research aims to contribute towards establishing the missing framework.

The reviewed literature does not only indicate the lack of a model selection framework, but it also shows that the Lean and VE hybrid methodology development process is complex. An examination of these complexities led to the following 6 conclusions:

- **Conclusion 1**: Lean and VE hybrid methodology is developed to achieve specific objectives. Additionally, the initial steps of the development process involve a comparative analysis of Lean and VE to determine strengths, weaknesses, similarities and differences.
- **Conclusion 2**: One of the most important factors when determining Lean and VE similarities and differences is scale. This is because some macro-scale similarities between Lean and VE are associated with micro-scale differences.
- **Conclusion 3**: The assessment of Lean and VE the strengths and weaknesses can be subjective and context dependent. And thus, a comparative analysis process which is purposed to determine strengths and weaknesses must include a consideration of organisational characteristics. This analysis step can yield strengths and weaknesses or advantages and disadvantages of Lean and VE within the organisational context.
- **Conclusion 4**: The similarities, differences, strengths, weaknesses, advantages and disadvantages of Lean and VE can be explored using a variety of Comparative Analysis Factors (CAF).
- **Conclusion 5**: The comparative analysis of Lean and VE *theory* and *practices* can be based on Principles/Concepts and Activities/Tools/Techniques.
- **Conclusion 6:** Lean and VE hybrid methodology can be implemented using three types of models, namely Interchangeable Use, Concurrent Use and Integrated Use models.

Furthermore, Lean and VE were designed separately without intending for them to be merged. Separate design results in differences that can be leveraged to achieve several hybrid methodology benefits. However, separate design can result in implementation barriers. Some of these barriers have been explored in literature, these include oversimplification, hyper-analysis, cost, time and sequencing. Some barriers are yet to be explored, these include differences in jargon, training requirements and resource requirements. This too contributes to the complexity of the Lean and VE hybrid methodology development process. Nevertheless, literature proposes the implementation of Lean and VE hybrid methodology because it has benefits that exceed those offered by the individual methodologies.

The authors who recommend Lean and VE hybrid methodology implementation include three types of implementation models in their proposals. Additionally, some authors provide implementation frameworks that show the convergence of Lean and VE literature, others provide implementation frameworks for one model type. However, the reviewed literature did not contain a framework that encompasses all three implementation models nor did it comprise of a model selection framework. A framework is one of the critical success factors in Lean and VE implementation (Haque & Chaudhuri, 2015; VM Services, 2017). A framework can be used to guide an implementation process and to guide decision-making processes. Individual Lean and VE methodologies have several frameworks which guide implementation and decision-making processes. Additionally, literature includes examples of the augmentation individual Lean and VE frameworks to develop hybrid methodology frameworks for Lean Six Sigma and Risk Management Integrated VE. These frameworks were established to facilitate successful hybrid methodology implementation. This study aims to establish a model selection framework to facilitate the successful implementation of Lean and VE hybrid methodology. A model section framework that does not only guide implementation but also guides decision-making processes. Current operational research trends show a movement to fact-based and 4IR-suitable methods such as CBA, MODM and MADM. These methods are structured based on alternatives and criteria. This study aims to ensure that the developed model selection framework aligns with current operational research trends.

3 Research Method

One of the important characteristics of a framework (the structure used to represent theory) is generalizability (Booth & Carroll, 2015). The primary research undertaken at Master's level is often characterized by small sample sizes and time constraints that do not facilitate the development of generalizable recommendations (Boland et al., 2017). Therefore, a Systematic Literature Review Methodology (SLRM) was selected for this study because it offers the benefits of large-scale primary research that facilitate the establishment of a framework that is more generalizable than those commonly undertaken at Master's level (Boland et al., 2017). The Systematic Literature Review definition adopted for this study is as follows (Fink, 2005, p. 3):

> A systematic, explicit, comprehensive and reproducible method for identifying, evaluating (appraising) and synthesizing the existing body of completed and recorded work produced by researchers, scholars and practitioners.

The purpose of this section is to discuss the methods that were employed to conduct the following research activities:

- Data collection
- Reporting: documenting the search strategy
- Data analysis
- Quality assurance: validity, reliability and applicability

3.1 Research Design

This research follows a 9-phase SLRM (Gough, 2007):

- Phase 1: Establishment of a review question
    - This review question is the research question for this study: "*What framework can provide guidance for the selection of either Interchangeable, Concurrent or Integrated Use models in Lean and VE hybrid methodology?"*
- Phase 2: The definition of *inclusion/exclusion* criteria
    - The criteria are based on the main research question
- Phase 3: Formation of a search strategy
    - The search strategy includes information data sources, type of literature reviewed (peer-reviewed or grey literature), the searching method, search words and the screening process
- Phase 4: Screening of literature

    - The aim of this phase is to determine whether the retrieved literature meets the *inclusion/exclusion* criteria
- Phase 5: Search strategy results reporting
    - The results are reported using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram**.** (PRISMA Statement, 2015)
- Phase 6: Critical appraisal
    - The included studies are critically appraised based on the comprehensiveness of and the quality of evidence
- Phase 7: Data extraction
    - The data are extracted according to a checklist which is compiled based on the expanded Lean and VE hybrid methodology development process outlined in Figure 3.
- Phase 8: Synthesis
    - The included studies are initially synthesized using narrative synthesis (Popay et al., 2006) followed by framework, aggregative and integrative synthesis (Booth et al., 2016) to facilitate framework development.
- Phase 9: Conclusion
    - All information is consolidated to produce and record an outcome that satisfies the research question.

3.2 Data Collection: Sampling

3.2.1 Sample

The intent of this study is to identify the models that represent Lean and VE hybrid methodology theoretical concepts. Based on the intent, this review can be defined as a Theory Mining Review (Okoli, 2015)**.** Specifically, this review is the simplest type of Theory Mining Review (TMR) called a Theory Landscaping Review (TLR). A TLR is applied to identify, extract and synthesize theoretical concepts/relationships (Okoli, 2015)**.** The targeted outcome of this research is the generation of a framework for Lean and VE hybrid methodology model selection. Thus, the two main characteristics of this research can be summarized as follows:

- A Theory Mining Review, specifically a Theory Landscaping Review (Okoli, 2015)
- A knowledge-building and theory-generating review (Finfgeld-Connett & Johnson, 2013)

The sample sought using SLRM is literature. When literature is sought for theory mining purposes, it must include peer-reviewed and grey literature to minimise publication bias and locate newly proposed concepts that may be “concealed” in grey literature sources (Okoli, 2015). Grey literature is suitably described by the type of document it represents. The document types include dissertations and theses,

conference proceedings, in-house and non-commercial journals, reports, websites, practitioner publications (*Document Types in Grey Literature*, 2004). The following documents types were sought to minimise publication bias and locate newly proposed concepts:

- Dissertations and theses
- Conference proceedings
- In-house and non-commercial journal papers
- Reports
- Websites
- Scholarly journal papers
- Practitioner publications

Overall, the sample reviewed in this study includes both peer-reviewed and grey literature. The sample includes both theoretical and empirical studies, this is because Lean and VE hybrid methodology can either be proposed in conceptual studies or applied in empirical studies. The sample is not restricted to studies in any setting (industry types, country or year), this is because Lean and VE hybrid methodology can be applied in various disciplines. The sample is limited to the English language.

3.2.2 Data Collection: The Search Strategy

Search Terms:

An SLRM theory search involves a search for concepts, synonyms and relationships (Okoli, 2015)**.** The two main concepts explored in this study are Lean and Value Engineering. These concepts are somewhat unique therefore the full-text search of these words was deemed appropriate for electronic searches (Okoli, 2015). Lean and Value Engineering have alternative names, this necessitates a search for synonyms through an iterative process that is only halted once no new or relevant studies were retrieved (Okoli, 2015). The Lean search synonyms were:

- Toyota Production System
- Continuous Improvement
- Kaizen

The Value Engineering search synonyms were:

- Value Methodology
- Value Analysis
- Value Management

The *AND* Boolean operator, a method for combining terms for search relationships (Booth et al., 2016), was used when searching for relevant Lean and VE relationships. The search was conducted by applying sixteen combinations shown in Table 4.

Table 4: Search Strategy Terms and Combinations

Combination Number	Search Term One	Boolean Operator	Search Term Two
1	Lean	AND	Value Engineering
2	Lean	AND	Value Methodology
3	Lean	AND	Value Analysis
4	Lean	AND	Value Management
5	Toyota Production System	AND	Value Engineering
6	Toyota Production System	AND	Value Methodology
7	Toyota Production System	AND	Value Analysis
8	Toyota Production System	AND	Value Management
9	Continuous Improvement	AND	Value Engineering
10	Continuous Improvement	AND	Value Methodology
11	Continuous Improvement	AND	Value Analysis
12	Continuous Improvement	AND	Value Management
13	Kaizen	AND	Value Engineering
14	Kaizen	AND	Value Methodology
15	Kaizen	AND	Value Analysis
16	Kaizen	AND	Value Management

Literature Sources:

Another vital aspect of the search strategy is the selection of sources. Lean and VE enjoy multidisciplinary application, therefore it was important to select databases that contain multidisciplinary peer-reviewed literature. Mahood et al. (2014) advise that the search for grey literature must include a search through web search engines, websites, institutional repositories, and expert contact, and Booth et al. (2016) propose that a grey literature search can include a search through grey literature databases and conference proceedings. Due to time constraints, access constraints and the multidisciplinary implementation of Lean and VE, the search strategy involved the use of the following sources and search engines:

- Scopus
- Emerald Insight
- Wiley Online
- Taylor and Francis
- ProQuest Central
- Google Scholar
- SAGE Journals Online

- Web of Science
- Google Search
- Research Gate
- WorldCat Dissertations and Theses
- Digital Archive of Theses and Dissertations including Current and Completed Research
- SAVE International Conference Proceedings
- Institute of Value Management Australia Website
- Hong Kong Institute of Value Management Website
- Lean Enterprise Institute Africa Website
- Lean Global Institute Website

Search Methods:

A sample that includes both peer-reviewed and grey literature requires search methods that are suited to both types of literature. The most suitable methods are free-text, bibliographic, citation and hand searching (Booth et al., 2016; Mahood et al., 2014). The search procedure was as follows:

- Free-text searching of electronic data: this was performed using the search combinations detailed in Table 4
- Bibliographic searching: this was conducted by hand searching the reference lists of the review articles
- Citation searching: this was achieved by using Google Scholar to search for any literature that cited the review articles
- Hand searching: this method was applied to search conference proceedings table of contents, websites and web-based organisational repositories

3.2.3 Reporting: Documenting the search strategy

The search process was documented to ensure that the SLRM meets transparency and reproducibility standards (Booth, et al, 2016). The documented elements of the search method are listed below (Rader et al., 2014):

- Date and time of the search
- Search timeframe (source coverage dates)
- Source
    - Database name
    - Website name
    - Seed article title and author (for bibliographic and citation searching methods)
    - Conference name

- Search terms
- Description of the search strategy
- Number of records retrieved

Table 5 contains a summary of the data collection process. The detailed process can be found in Appendix 1.

Table 5: Summary of the literature collection method

Source	**Search Coverage Date**	**Search Method**	**Search Strategy**	**Number of Records Retrieved**
Scopus	1960 - 03/06/2019	Free-text searching	Searched all fields using 16-word combinations (see Table 4).	573
Emerald Insight	1994 - 03/06/2019	Free-text searching	Advanced searched all fields (articles, chapters, case studies) using 16-word combinations.	1 087
Wiley Online	1997- 05/06/2019	Free-text searching	Advanced searched all fields (journals only) using 16-word combinations.	510
Taylor and Francis	1997- 07/06/2019	Free-text searching	Advanced searched all fields (articles only) using 16-word combinations.	878
ProQuest Central	All available dates until 12/06/2019	Free-text searching	Advanced searched all fields (all document types) using 16-word combinations.	14 274
Google Scholar	All available dates until 20/06/2019	Free-text searching	Advanced searched all fields (all document types) using 16-word combinations.	95 709
Google Scholar	28/06/2019-05/08/2019	Citation searching	Searched by title and author using 24 articles (seed articles) that were selected for review. (Borgianni et al., 2010; Cell & Arratia, 2003; Chakravartty, 1991; De Hemmer, 2012; Ekanayake & Sandanayake, 2017; Ho et al., 2000; Kheradia, 2011; Lee et al., 2016; Lehman & Reiser, 2004; Mandelbaum et al., 2010; Musa et al., 2016; Nassey, 2004; Nayak, 2006; Odedairo & Bell, 2010; Ogunbiyi et al., 2011; Parker, 2015; Prahladaraj, 2004; Sacadura & Tenera, 2011; Salvatierra-Garrido et al., 2008; Shekari & Fallahian, 2007; Thorsen,	160

			2005; Watson, 2005; Wixson, 2005; Wohnhas, 2014)	
24 articles (seed articles) that were selected for review. (Borgianni et al., 2010; Cell & Arratia, 2003; Chakravartty, 1991; De Hemmer, 2012; Ekanayake & Sandanayake, 2017; Ho et al., 2000; Kheradia, 2011; Lee et al., 2016; Lehman & Reiser, 2004; Mandelbaum et al., 2010; Musa et al., 2016; Nassey, 2004; Nayak, 2006; Odedairo & Bell, 2010; Ogunbiyi er al., 2011; Parker, 2015; Prahladaraj, 2004; Sacadura & Tenera, 2011; Salvatierra-Garrido et al., 2008; Shekari & Fallahian, 2007; Thorsen, 2005; Watson, 2005; Wixson, 2005; Wohnhas, 2014)	28/06/2019 – 05/08/2019	Bibliographic searching	Manually searched the reference lists of the articles selected for review.	565
SAGE Journals Online	1999 - 14/06/2019	Free-text searching	Advanced searched all fields (all document types) using 16-word combinations	366
Web of Science	1945 - 17/06/2019	Free-text searching	Advanced searched all fields (all document types) using 16-word combinations	32
WorldCat Dissertations and Theses	1955 - 18/06/2019	Free-text searching	Searched all fields using 16-word combinations	1789
Digital Archive of Theses and Dissertations including Current and Completed Research	All available dates until 19/06/2019	Free-text searching	Searched subject using 16-word combinations	134
SAVE International Conference Proceedings	2005-2018	Manual searching	Manually searched the conference proceedings Table of Contents (by title).	500

Institute of Value Management Australia Website	All available dates until 21/06/2019	Manual searching	Manually searched the web-based organisation publications (by title). Searched the member papers found on the "Knowledge Bank" webpage.	64
Hong Kong Institute of Value Management Website	2000, 2005, 2006, 2010 and 2012	Manual searching	Manually searched the conference proceedings Table of Contents (by title).	108
Lean Enterprise Institute Africa Website	2018-2019	Manual searching	Manually searched the summit proceedings Table of Contents (by title). Manually searched the "Knowledge Center" webpage.	36
Lean Global Institute Website	All dates available until 21/06/2019	Manual searching	Manually searched the "Knowledge Center" webpage.	0

Some word combinations (see Table 4) yielded more than 200 records (Google Scholar and ProQuest Central) during free-text searching. When this occurred, only the first 200 retrieved records were screened. As a result, 115 352 records were retrieved through free-text searching, however, only 11 048 of those records were subjected to the screening process. Additionally, some literature sources produced records that did not include the full-text article, when this occurred, the full-text article was retrieved by applying the following actions:

- Searched Google to find the journal that published the article or the institution responsible for the research
- Searched the University of the Witwatersrand (Wits) journal database
- Searched Research Gate and requested the full-text article from the author
- Contacted the institutions (SAVE International/Hong Kong Institute of Value Management/University of Tennessee) that were responsible for the research
- Requested the full-text article using the Wits Inter-Library Loan system

3.3 Data Analysis: Practical Screening, Critical Appraisal, Data Extraction and Synthesis

The SLRM selection process can occur in one or two stages. During the one-stage SLRM selection process, the retrieved records are only subjected to a process called practical screening. During the two-stage selection process, practical screening and the critical appraisal are both used as selection processes (Booth et al., 2016). The one-stage process was applied in this study because the two-stage process is not required for Theory Landscaping Reviews (Okoli, 2015). The practical screening process

was used to select and reject studies based on relevance and the critical appraisal process was used to assess the quality of the studies, however, no studies were rejected based on quality.

3.3.1 Practical Screening

During the practical screening process, the retrieved records were examined for relevance using the *inclusion/exclusion* criteria (Okoli 2015; Booth et al., 2016). The in*clusion/exclusion* criteria were as follows:

- Inclusion criteria:
  - The document must be written in the English language
  - The document content must include a discussion of both Lean (or its synonyms) and Value Engineering (or its synonyms) concepts
  - The document content must include the proposal (or use, if it is an empirical study) of Lean and Value Engineering hybrid methodology
  - The proposal (or use) of Lean and VE hybrid methodology must be based on a documented logical model generation logic (see Figure 3) that indicates model generation guiding principles (the principles may be implicit or explicit)
- Exclusion criterion:
  - Documents that include Lean (or its synonyms) and Value Engineering (or its synonyms) hybrid methodology but do not include and a model generation logic (see Figure 3).

The criteria were applied to assess the literature by title, abstract and full text according to the following steps:

- During Free-text searching, only the first 200 records (retrieved from each word combination described in Table 4) were screened. As a result, only 11 048 of the 115 352 free-text searching retrieved records were screened.
- 12 481 records were retrieved through the application of four searching methods (free-text, manual, bibliographic and citation searching). The records were first assessed based on the title, some papers were excluded at this stage to produce a resultant 1 022 documents.
- The 1 022 documents were then assessed based on abstract, some were excluded at this stage to give a resultant 292 documents.
- The 292 documents were then subjected to a deduplication process, this resulted in the selection of 102 documents for full-text screening.
- Of the 102 documents selected for full-text screening, only 82 documents were screened because 21 full-text documents could not be obtained due to financial and time constraints.

- The 82 full-text documents were then assessed based on full-text reading and the *inclusion/exclusion* criteria, some were excluded at this stage which yielded a resultant 24 papers that were selected for review.

This process is summarized using the PRISMA flow diagram in Figure 9 (PRISMA Statement, 2015) and the detailed process can be found in Appendix 1.

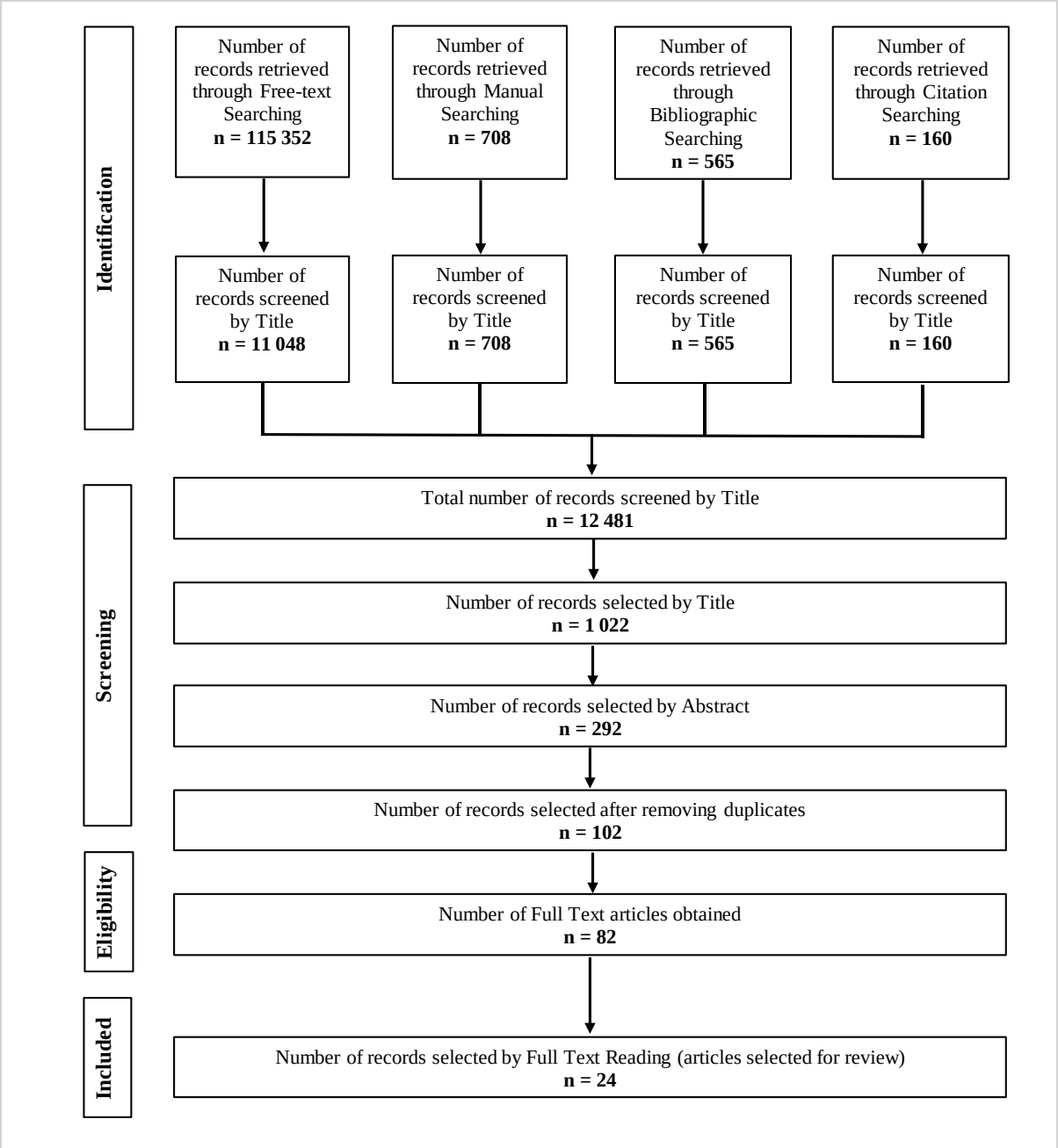


Figure 9: The PRISMA flow diagram

3.3.2 Critical Appraisal

The purpose of a critical appraisal process can be two-fold, to prioritise papers based on their quality and to exclude because of substandard methodology quality (Booth et al.; 2016). A quality appraisal is not recommended for theory mining reviews because they are exploratory and seek concepts that are supported by arguments (Okoli, 2015), but given that this study sought to locate model recommendations in order to develop a theoretical framework, it was deemed necessary to include a critical appraisal process.

The quality of a study is a function of validity, reliability and applicability. The validity of a study refers to the possibility that it will generate unbiased results. Reliability refers to whether the results are reproducible or repeatable, reliability ensuring methods minimise the effect of chance. Applicability refers to the strength of the recommendations (Booth et al., 2016; Shea et al., 2009). A critical appraisal checklist was established to assess these three characteristics. The critical appraisal checklist contains factors that are organized into three categories, namely applicability factors, validity factors and reliability factors (shown in Table 6), this was done to enable quality assessment (Booth et al., 2016).

The quality was rated based on each study's compliance to the factors listed in Table 6: high compliance was denoted by a (3) score, medium compliance was denoted by a (2) score, low compliance was denoted by a (1) score and non-compliance was denoted by a (0) score. The classification reasoning was provided in the analysis column (Booth et al.; 2016). The detailed analysis and scoring for all 24 review articles can be found in Appendix 2; the summarised scores can be found in section 4.3.

Table 6: Critical Appraisal Checklist

Factor Group	Factor Number	Factor Name	Factor Description	Analysis	Rating: Weight Factor (0- None, 1-Low, 2-Medium & 3-High)
Applicability	1	Topic	Themes contained in the title and abstract	**Rating 0**: N/A, **Rating 1**: N/A, **Rating 2**: The theme refers to the integration of one or more Lean or VE components and/or the theme refers to one/two model types and/or the theme refers to one application area/function with an organisation, **Rating 3**: The theme refers to the integration of Lean and VE methodologies in their entirety and/or the theme refers to application in all areas of an organisation or application in an entire industry and/or the theme refers to all three models types	
	2	Discipline	Discipline in which the study was set or in which the study audience belongs	**Rating 0**: N/A, **Rating 1**: Study set in small/emerging sector and/or only involves one discipline, **Rating 2**: Study is based in a large sector and/or involves multiple disciplines but is limited to a specific organisation type/problem type/product type/service type, **Rating 3**: Study is based in a large sector and/or involves multiple disciplines. Note: a large sector is a sector which contributes significantly to GDP	

	3	Context	The environment in which the study was conducted	**Rating 0**: N/A, **Rating 1**: The study is limited to a specific product type and/or is limited to one SME and/or is limited to a small department within one organisation, **Rating 2**: The study is conducted in a medium/large functional areas/departments/offices or in multiple SME's and/or is limited to a specific country/organisation type, **Rating 3**: The study is conducted in large/global organisations or is conducted for an entire industry/sector/discipline or is conducted in multiple functional areas/departments and/or the study is intended for multiple countries or the study is proposed for all organisations	
	4	Strength of Recommendations	Suitability of recommendations to application based on context, conditions and analyses	**Rating 0**: N/A, **Rating 1**: The recommendations are based on a research methodology that has high compliance to *only one* of the three factors (validity/reproducibility/applicability), **Rating 2**: The recommendations are based on a research methodology that has high compliance to *two* of the three factors (validity/reproducibility/applicability), **Rating 3**: The recommendations are based on a research methodology that has high compliance to *all three* factors (validity/reproducibility/applicability)	
Validity	5	Author	Author qualifications, experience and previous related work	**Rating 0**: N/A, **Rating 1**: N/A, **Rating 2**: Research was conducted to obtain a Masters qualification, **Rating 3**: Research was conducted to obtain a PhD qualification or the author (Practitioner) holds a degree, has more than 5 years' experience and has Lean/VE certification or the author (Academic) has a post-graduate degree and has published at least 5 times	

	6	Literature Source	The journal, conference proceedings or database where literature was published	**Rating 0**: N/A, **Rating 1**: N/A, **Rating 2**: Grey literature, **Rating 3**: Peer-reviewed scholarly journal	
	7	Study Design	The study design type - Qualitative: Case Study, Ethnography, Phenomenological, Grounded theory, Content Analysis; Quantitative: Observation, Correlation, Developmental, Survey, Experimental or Mixed Methods	**Rating 0**: N/A, **Rating 1**: N/A, **Rating 2**: Qualitative, **Rating 3**: Mixed Methods or Quantitative	
	8	Sample Suitability	Size, type and characteristics of the sample	**Rating 0**: N/A, **Rating 1**: Opinion of 1 expert and/or insufficient literature reviewed or sample size is less than 10, **Rating 2**: SME context or 10< sample size <30 and/or satisfactory number of studies reviewed, **Rating 3**: Large/global enterprise or based on the opinion of at least 5 experts or comprehensive number of studies reviewed or the sample size is ≥ 30	
	9	Data Collection Methods	Methods utilised to collect the sample	**Rating 0**: Methods not specified, **Rating 1**: N/A, **Rating 2**: The use of Lean/VE data collection methods and/or Interviews and observations or purposive sampling methods, **Rating 3**: The use of random sampling methods or systematic literature review conducted by at least two authors	

	10	Data Analysis Methods	Methods utilised to analyse the data	**Rating 0**: N/A, **Rating 1**: Literature review analysis methods completed by one expert, **Rating 2**: Lean and VE analysis methods or a combination of literature review and case study methods or Content Analysis or based on opinions at least 5 experts, **Rating 3**: A combination of comprehensive Qualitative and Quantitative methods	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	An analysis of the study characteristics. Introduction: Purpose & motivation; Content: Claims, evidence, counterevidence, literature review; Presentation: clear structure, logical idea flow; Theoretical foundation; Data Analysis Process: assertions & support; Conclusion: applicability, limitations, implications for future research	Apply a rating based on the number of Hirscheim (2008) components evident in the research paper	
	12	Overall Aim to minimise bias	Explicit methods applied to minimise bias	**Rating 0**: Bias minimisation methods not presented, **Rating 1**: Bias minimisation methods not presented but study limitations were outlined or evidence can be deduced from the article or the proposed model was verified using case study method, **Rating 2**: Bias minimisation methods not presented but there is evidence of rigour in	

				sample collection and analysis, **Rating 3**: Bias minimisation methods are presented	
Reproducibility	13	Data Collection Methods	Clarity and auditability of data collection methods	**Rating 0**: Data collection methods are not clear and therefore not auditable, **Rating 1**: Data collection methods are clear but not auditable, **Rating 2**: The data collection methods are clear and auditable. However, auditing cannot be completed outside of the research setting, **Rating 3**: The data collection methods are clear and auditable.	
	14	Number of Factors Explored	The determination whether sufficient data was reviewed	Rating should be applied based on the study context.	
	15	Number of Studies Explored	The determination whether sufficient literature was reviewed	**Rating 0**: N/A, **Rating 1**: Low number of studies reviews, **Rating 2**: Satisfactory number of studies reviewed, **Rating 3**: High number of studies reviewed	
	16	Data Analysis Methods	Clarity and auditability of data analysis methods	**Rating 0**: N/A, **Rating 1**: A low number of the analysis components are clear and auditable, **Rating 2**: A satisfactory number of the analysis components is clear and auditable, **Rating 3**: A high number of the analysis components is clear and auditable	
Total Score					

3.3.3 Data Extraction

The theoretical foundation of this study is the Lean & VE hybrid methodology development process (illustrated by Figure 3), therefore it was deemed necessary to create a data extraction checklist based on Figure 3. The checklist that is utilised to extract the data is shown in Table 7. The data extraction results are included in chapter 5.

Table 7: Data Extraction Checklist

	Author	**Type**	**Description**
Lean Theory			
Lean Practices			
Similarities & Differences Comparative Factors			
Lean & VE Similarities and Differences		Macro Similarity	
		Micro Difference	
		Difference	
Strengths & Weaknesses Comparative Factors			
Lean & VE Strengths and Weaknesses			
Lean & VE Implementation Models		Interchangeable Use	
		Concurrent Use	
		Integrated Use	

3.3.4 Synthesis

Synthesis is a formal process. The purpose of this study is to *identify* and *analyse* Lean and VE hybrid methodology models and their guiding principles and to use the identified relationships to *develop* a model selection framework. Narrative and framework synthesis were selected to identify and analyse Lean and VE hybrid methodology models and their principles. Narrative synthesis is a review of findings from various studies based on words and text to synopsize and describe the findings (Popay et al., 2006). The employed narrative synthesis method is based on three elements and their techniques (Popay et al., 2006).

- Element 1: The development of theory change (Technique: based on the process illustrated in Figure 3)
- Element 2: The development of the preliminary synthesis of findings (Techniques: textual description, tabulation and data translation techniques)
- Element 3: The exploration of relationships within and between studies

A data extraction tool (Table 7) was used to conduct framework synthesis. Framework synthesis involves textual analysis and the grouping of data into a structure (Booth et al., 2016). After narrative and framework synthesis was completed, aggregative synthesis and integrative synthesis were applied to develop the selection framework. Aggregative synthesis and integrative synthesis involve the integration of principles and themes and therefore facilitate the development of a framework (Booth et al., 2016).

3.4 Quality Assurance: Validity, Reliability and Applicability

As mentioned in section 3.3.2, quality is a function of validity, reliability and applicability (Booth et al., 2016). The quality of an SLRM study is influenced by both the quality of the individual studies that are included in the review and the methods applied to conduct the systematic literature review itself.

Since the validity, reliability and applicability of a systematic review are influenced by both individual included studies and by the methods employed in the review, the methods employed in this study address both elements. The quality of the included studies was assessed using the critical appraisal checklist described in section 3.3.2.

The validity of SLRM is influenced by bias. There are various sources of bias in systematic review methodology. The bias sources and the applied preventative measures are outlined in Table 8.

Table 8: The Sources of Bias in SLRM

Bias Type	**Source**	**Minimisation method applied**
Reporting bias	Selective distribution of results based on their nature (Drucker et al., 2016).	Result reporting using the standardized PRISMA checklist (PRISMA Statement, 2015).
Publication bias	Discriminatory submission or acceptance of research based on the type of results (Booth, et al., 2016).	Literature search strategy includes free-text, bibliographic, manual and citation searching to increase the chance of locating unpublished literature. The inclusion of grey literature.
Literature source bias	Database indexing (Booth et al., 2016), and Google filtering based on popularity, location and search history (Mahood et al., 2014).	Signed out of the Google account to conduct Google searching to minimise the effects of search history. However, it is difficult to minimise the effects of popularity and location filtering.
Reviewer bias	Research is conducted by one reviewer (Borrego et al., 2014).	It is difficult to minimise this bias at Master's level due to time constraints. However, enough detail is provided to allow readers to discern whether the conclusions are warranted. Explicit SLRM techniques are applied to ensure transparency and enable reproducibility testing.

The heterogeneity of the included studies can also affect the quality of the systematic review (Drucker et al., 2016); these differences are assessed and addressed during data extraction and synthesis phases of this systematic review.

The methods employed in a systematic review are designed to ensure reproducibility. A systematic literature review follows a methodology that provides clarity and facilitates auditability. The review research question, *inclusion/exclusion* criteria and selected literature sources all provide clarity of scope. All these components contribute to the explicit description of the boundaries of the research, and this enables reproducibility. Additionally, the employed synthesis techniques provide clarity in the results analysis stage. Similarly, the standardized reporting methods, explicit data extraction methods and explicit literature synthesis methods ensure auditability and thus facilitate reproducibility. (Booth et al., 2016)

A notable proportion of the systematic review components facilitate reproducibility, however certain components of the review method can also limit reproducibility. For instance, this study makes use of Google within its search strategy, and Google filters results based on popularity**,** location and search history (Mahood et al., 2014), this compromises reproducibility. For the purposes of this study, Google was utilised to minimise publication bias. The Google search strategy processes are communicated through an explicit report (Appendix 1) to communicate context-based study limitations.

In summary, theory mining and theory generating SLRM was employed to fulfil the objectives of this study. An expansive literature search strategy was applied to minimise bias and to locate concealed concepts. The expansive literature search strategy involves the use of four search methods (free-text, bibliographic, citation and manual searching) to collect both peer-reviewed and grey literature. 12 481 retrieved articles and citations were examined for relevance using the practical screening process and *inclusion/exclusion* criteria, this resulted in the selection of 24 articles. After the practical screening, the quality of the selected articles was determined in the critical appraisal process. The final step involves data extraction and synthesis where relevant concepts are extracted and synthesized to develop the model selection framework.

4 Overview of Articles

The purpose of this section is to present an overview of the study sample. A total of 24 articles were selected for review based on the *inclusion/exclusion* criteria of this study. The overview is presented as follows:

- Section 4.1: The article content is introduced through an examination of the research purpose and the concepts contained in the title and abstract.
- Section 4.2: The graphical analysis is utilised to discuss the context of the articles. Context is a function of author profession, sector in which the study was conducted, publisher, year of publication and document type.
- Section 4.3: The quality of the research articles is discussed through an analysis of the study design and the results of the critical appraisal process.

4.1 Introducing the review articles

The purpose of this section is to introduce the 24 articles that were selected for review. The article author, year of publication, title and summary are used to introduce the selected articles. The article summaries were created using the research purpose as well as the themes contained in the article title and abstract.

This sample is comprised of peer-reviewed and grey literature that was published by practitioners and academics between the year's 1991 and 2017 (Table 9). The articles are presented in chronological order. The authors of these articles all recommend the integration of Lean and VE. However, they recommend this integration for the achievement of varying purposes based on the requirements of various sectors, disciplines and enterprise sizes. The sample is comprised of both theoretical and empirical research.

Table 9: Selected Research Articles

Number	Authors	Title	Summary
1	(Chakravartty, 1991)	Value Analysis and Value Engineering as a cost reduction tool and its relation with JIT manufacturing	Value Engineering and Just in Time (JIT, a Lean technique) integration for the purposes of cost reduction and quality improvement. The purpose of the study was to show the benefits of the combined implementation of VE and JIT through the application of a case study method in the manufacturing environment.
2	(Ho et al., 2000)	Integration of Value Analysis and Total Quality Management: The way ahead in the next millennium	The integration of Value Engineering and Total Quality Management (TQM- a Lean technique/tool) to exhaust the full potential of TQM. The purpose of the study was to explore the common areas of VE and TQM and to investigate and recommend integration opportunities.
3	(Cell & Arratia, 2003)	Creating value with Lean thinking and Value Engineering	The use of Lean and VE in a collaborative and synergistic manner to affect the cost, value, organisational culture, productivity and customer relations. The purpose of the paper was to present the concept of Lean and VE hybrid methodology.
4	(Lehman & Reiser, 2004)	Maximizing value & minimizing waste: Value Engineering & Lean Construction	Achieving a balance between value maximisation and waste minimisation in the construction industry through the application of Lean Construction and Value Engineering. The purpose of the paper was to show that the integration of Lean and VE can be used (is used by The Boldt Company) to achieve the required balance between waste minimisation and value maximisation.
5	(Nassey, 2004)	Implementation of Lean method and Value Analysis in the sandblasting production shop at Intersign Corporation	The application of Lean and VE to improve layout and process in a sandblasting production shop. The purpose of the study was to evaluate the layout and process of the company's sandblasting department and to provide improvement recommendations using Lean and VE principles.

6	(Prahladaraj, 2004)	Integration of Lean Manufacturing and Value Engineering techniques to improve the internal distribution system in a manufacturing company	The application of Lean and VE to improve the internal distribution system of a company in the manufacturing industry. The purpose of the study was to develop a Lean distribution system and provide improvement recommendations using Lean and VE principles.
7	(Thorsen, 2005)	Value Stream Mapping & VM	The application of Lean's Value Stream Mapping to Value Methodology at General Motors. The purpose of the paper was to demonstrate the application of VSM techniques within Value Engineering.
8	(Wixson, 2005)	A Value Management Approach to Improving Quality Performance	The use of VE's FAST diagram and other analytical techniques to solve continuous improvement problems within Quality Assurance operations. The purpose of the study was to apply VE's Functional Analysis (FAST diagram) and Lean's Root Cause Analysis and FMEA to identify areas for improvement and to propose solutions in Quality Assurance.
9	(Watson, 2005)	Putting value back into engineering	Improving the Value Engineering framework through integration with other methods (e.g. Lean). The purpose of the study was to recommend ways to improve the VE approach in a manner that aligns it with the CI developments of the three decades that preceded the year 2005.
10	(Nayak, 2006)	Lean Manufacturing and Value Management convergence of divergent tools	The integration of Lean Manufacturing and VE to achieve synergistic benefits in the manufacturing industry. The purpose of the study was to explore Lean and VE history and theoretical concepts, conduct a comparative analysis of Lean and VE and introduce a Lean and VE integrated model.
11	(Shekari & Fallahian, 2007)	A new approach to linking Value Engineering & Lean Methodology	The linking of VE and Lean in a sequenced manner to achieve synergistic benefits. The purpose of the study was to develop an integrated Lean and VE model that would improve product functions, increase customer satisfaction and eliminate waste.

12	(Salvatierra-Garrido et al., 2008)	Social housing in Chile: Opportunities to apply value concept in early stage of projects	The integration of Lean and VE in the early stages of construction projects in low-income social housing in Chile.
13	(Borgianni et al., 2010)	Process Value Analysis for business process re-engineering	The design of a new methodology to achieve value delivery and support Business Process Re-engineering activities. The purpose was to propose a new methodology suitable for application within competitive mature industries. This method features Lean and VE techniques and was tested in the manufacturing industry.
14	(Mandelbaum et al., 2010)	Value Engineering Synergies with Lean Six Sigma	An examination of potential synergies between VE and Lean Six Sigma. The purpose of the research was to examine the leverage opportunities that facilitate the integration of Lean Six Sigma and VE.
15	(Odedairo & Bell, 2010)	Framework for introducing and implementing value methods: a novel toolkit for small and medium scale industries in developing nations	The integration of techniques found in value methods (Lean and VE included) to develop a suitable method for small to medium enterprises in developing countries. The purpose of the study was to develop a function orientated value method through the integration of various techniques to facilitate implementation in SMEs in developing countries.
16	(Kheradia, 2011)	TALEVAS model: an integrated quality methodology	An integrated approach to quality management in any organisation through combining Lean, VE and other improvement methods. The purpose of the study was to develop and propose a quality management model that integrates Lean, VE and other improvement models.
17	(Ogunbiyi et al., 2011)	Innovative Value Management: assessment of Lean Construction implementation	The implementation of Value Management approaches in Lean Construction (LC). The purpose of this study was to conduct an examination of the value maximisation challenges in LC, to propose a Value Management approach to LC and to explore the concept of Value Management in LC.

18	(Sacadura & Tenera, 2011)	Integrating Value and Lean Management in manufacturing processes	The development of a VE (FAST diagram) and Lean (VSM) integrated model in the manufacturing industry. The purpose of the study was to propose and validate a Lean and VE integrated model, one that effectively reduces Lean gaps.
19	(De Hemmer, 2012)	Value(s) and management: There's value everywhere!	Combining various methods that are utilised to manage value, this includes Lean and VE. The purpose of the paper was to propose a "legitimate" method to manage value using combined improvement methods.
20	(Wohnhas, 2014)	Value management in Lean product development	The purpose of this study was to describe and share the Whirlpool Corporation experience in the implementation of Value Management in Lean Product Development within the project definition phase of the Project Life Cycle.
21	(Parker, 2015)	Lean as a value enhancing methodology	The integration of Lean and VE because of their complementary features. The purpose of the study was to show that Lean and VE are complementary and can be suitably integrated to improve value maximisation efforts.
22	(Lee et al., 2016)	Using ICT to Improve Service Quality	A VE based method that involves the integration of Failure Mode and Effect Analysis (FMEA), Lean and Six Sigma to support the configuration of the customer service centre and improve call-centre service quality. The purpose of the study was to develop, test and propose a VE based integrated tool to improve service quality.
23	(Musa et al., 2016)	Where Lean Construction and Value Management meet	The integration of Lean Construction and VE to achieve synergy in value definition. The purpose of the study was to investigate the value concept within Lean Construction in order to determine opportunities where the two methods can be integrated to obtain synergistic benefits.
24	(Ekanayake & Sandanayake, 2017)	LiVE approach: Lean integrated Value Engineering for the construction industry	Lean and Value Engineering integration to achieve synergy within the construction industry. The purpose of the research was to develop Lean integrated VE synergy concepts suitable for implementation in the construction industry.

4.2 Outlining the Research Context

The purpose of this section is to discuss the context of the literature sample. Context provides the scope and indicates the limitations of the recommendations. Additionally, it enables the reader to determine applicability. Context is provided through the classification of the 24 articles based on author profession (at the time the research was conducted), the sector in which the study was conducted, publisher, year of publication, study design and document type.

4.2.1 Article Classification by Sector

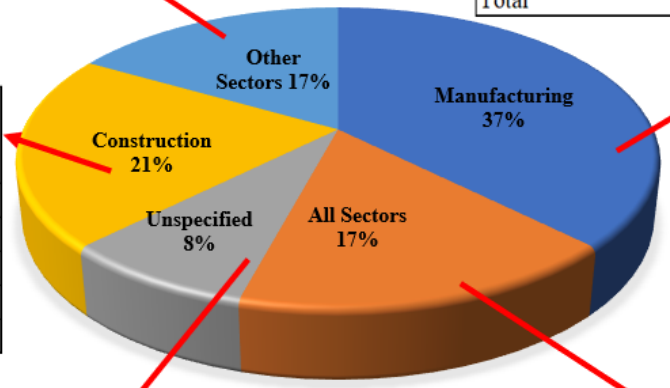
Lean and VE currently enjoy multidisciplinary implementation. However, as outlined in chapter 2, these CI methodologies originated in the manufacturing industry. The formation of a hybrid methodology is one of the ways in which CI is evolving. It is therefore important to determine whether this evolution is limited to the sector in which these methodologies originated (manufacturing) or if this evolution is multidisciplinary as well.

Figure 10 shows that the majority (58%) of the research included in this review was conducted in the manufacturing and construction context. Additionally, 7% of the included papers were not limited to a specific context and 8% were proposed to be suitable for all sectors. This means that a quarter of the included research was conducted in a manner that is applicable to all sectors. The sectors in which the included research was conducted are not as expansive as the sectors in which individual Lean and VE are currently implemented. However, the research was conducted in various areas, these areas include Quality Management, Project Management, Product/Service/Project Life Cycle Management, Production, Business Process Re-engineering, Customer Service Centres, Value Definition, Sustainability Projects and Administration. 6 articles comprised of research that was not limited to a specific area.

Other Sectors: Application Areas Other Sectors = Public Sector (Department of Energy) + Product & Service Sector + Construction, Product & Service Sectors + Service Sector)	Number of Articles	Percentage
Quality Management	1	25%
Business Process Re-engineering	1	25%
Product, Service & Project Life Cycle Management	1	25%
Customer Service Centre	1	25%
	4	100%

Manufacturing: Application Area	Number of Articles	Percentage
Design	2	22%
Quality Management	1	11%
Production	2	22%
Administration	1	11%
Unspecified	1	11%
SME functions (developing countries)	1	11%
Project Management	1	11%
Total	9	100%

Construction: Application Area	Number of Articles	Percentage
Unspecified	2	40%
Project Management	1	20%
Sustainability Projects	1	20%
Value Definition	1	20%
Total	5	100%



Unspecified: Application Areas	Number of Articles	Percentage
Unspecified	1	50%
Goods, Services and Production	1	50%
Total	2	100%

All Sectors: Application Areas	Number of Articles	Percentage
Unspecified	2	50%
Quality Management	1	25%
Management	1	25%
Total	4	100%

Figure 10: Sector-based Distribution of Review Articles

As outlined in chapter one, another form of Lean and VE evolution is the time-based spread from manufacturing to other sectors. Considering this characteristic of individual Lean and VE methodologies, it is necessary to determine whether the Lean and VE hybrid methodology research included in this study exhibits a similar attribute. The oldest research included in this review was conducted in the manufacturing industry in 1991 and the most recent research included in this review was conducted in the construction industry in 2017 (Figure 11). Between 1991 and 2017, the other twenty-two articles describe research that was deemed applicable for the product and service sectors, the public sector, the construction sector and all sectors (Figure 11). Therefore, the literature sample included in this study exhibits the outlined evolution attribute. Although the spread is not as expansive as that of individual Lean and VE methodologies.

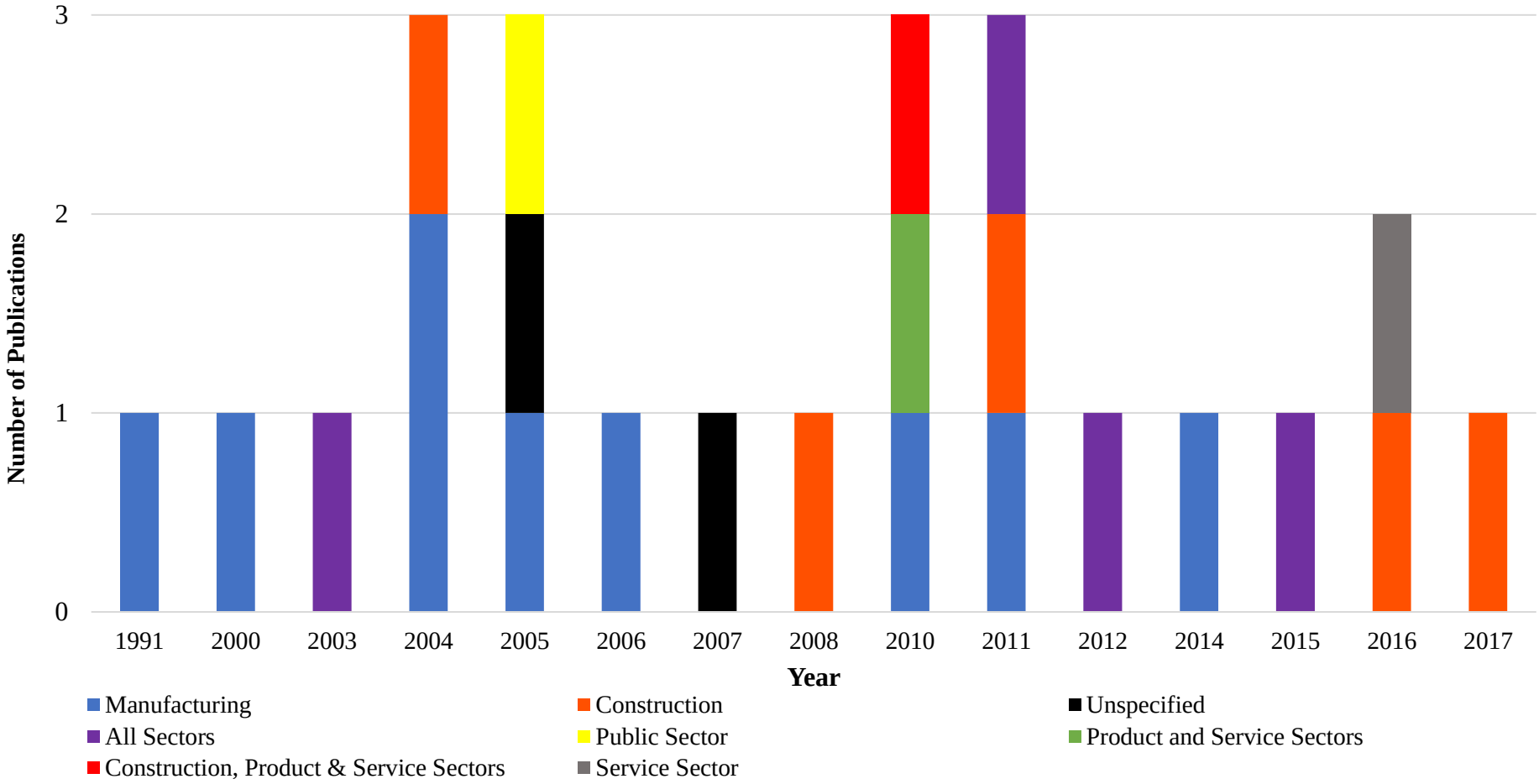


Figure 11: Sector-based Number of Publications per year (1991-2017)

In summary, the sector-based analysis revealed that the 24 selected Lean and VE hybrid methodology research articles feature multi-sectoral and multidisciplinary perspectives, although these may not be expansive due to the limitations in the *inclusion/exclusion* criteria applied in this study.

4.2.2 Article Classification by Author Profession

It is argued that practitioners and academics have different incentives, interests and logic and this contributes to differences in the manner in which they define and approach problems (Bartunek & Rynes, 2014). It is proposed that academic approaches maximise rigour and the practitioner approaches maximise relevance. This review includes literature that has been published by both practitioners and academics. Therefore, the purpose of this subsection is to analyse the 24 review articles based on author profession to explore the balance between rigour and relevance.

67% of the review articles were written from the academic perspective and 33% were written from the practitioner perspective (Figure 12). This indicates that the sample is more rigorous than relevant.

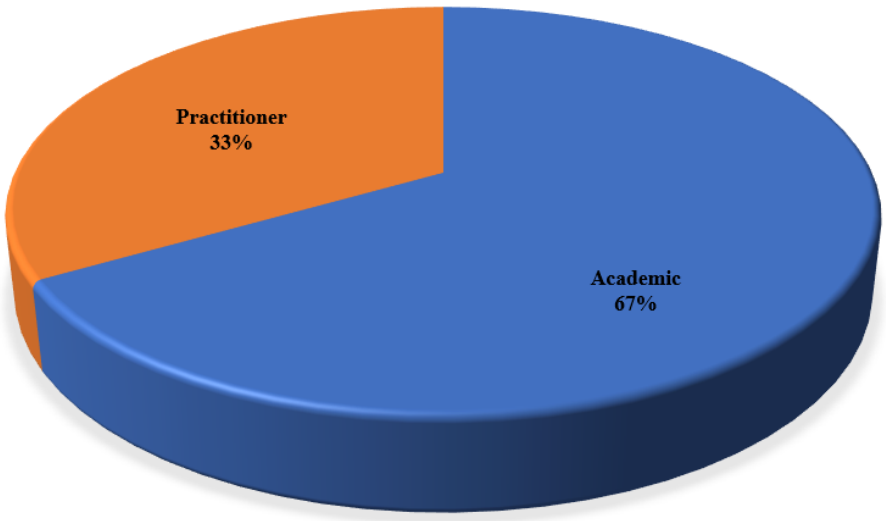


Figure 12: Distribution of Articles by Author Profession

Since practitioners and academics are said to approach problems in different ways, the research approaches of the review articles were analysed to determine whether any notable differences exist within the sample. 25% of the review articles propose the integration of the complete Lean methodology with the complete VE methodology to benefit from their complementary characteristics, to realise synergistic benefits or to overcome weaknesses (Cell & Arratia, 2003; Ekanayake & Sandanayake, 2017; Mandelbaum et al., 2010; Nayak, 2006; Parker, 2015; Watson, 2005). The authors of these 6 articles were mostly (66%) practitioners. All 6 articles are theoretical research papers that propose the use of Lean and VE hybrid methodology without the support of empirical evidence (application).

On the other hand, 75% of the review articles propose the integration of components of Lean with components of VE to achieve context-specific objectives (Borgianni et al., 2010; Chakravartty, 1991; De Hemmer, 2012; Ho et al., 2000; Kheradia, 2011; Lee et al., 2016; Lehman & Reiser, 2004; Musa et al., 2016; Nassey, 2004; Odedairo & Bell, 2010; Ogunbiyi et al., 2011; Prahladaraj, 2004; Sacadura & Tenera, 2011; Salvatierra-Garrido et al., 2008; Shekari & Fallahian, 2007; Thorsen, 2005; Wixson, 2005; Wohnhas, 2014). Most (78%) of these 18 articles were written by academics. Most (61%) of these articles are empirical research papers that include the application of Lean and VE hybrid methodology models through case study research methodology. Based on these differences, it can be concluded that there are notable variations between the research conducted from the academic perspective and the research conducted from the practitioner perspective.

In summary, this study includes research conducted by academics and practitioners. The majority of the review articles were written by academics and 33% were written by practitioners. For this particular sample of literature, the academic research favoured empirical research methods and the practitioner research favoured theoretical research methods.

4.2.3 Article Classification by Publisher and Document Type

This study aimed to analyse various types of Lean and VE hybrid methodology models and their principles, to aggregate and integrate these principles and to develop a selection framework. Based on this objective, this Systematic Literature Review (SLR) can be regarded as aggregative and theory generating. Exhaustive search methods are recommended for aggregative SLR's and expansive search methods are recommended for theory generating SLR's (Finfgeld-Connett & Johnson, 2013). In this study, four literature search methods were applied to obtain both peer-reviewed and grey literature from a variety of multidisciplinary sources, this was done to ensure that this review has the closest possible proximity to exhaustiveness and expansiveness (Finfgeld-Connett & Johnson, 2013). The purpose of this section is to analyse the 24 selected articles based on document type and publisher to evaluate the yield produced by the employed data collection methods.

The employed data collection methods resulted in a sample that comprises of 5 document types namely, scholarly journal papers, dissertations and theses, conference papers by practitioners, conference papers by academics, and reports. The 24-article sample is comprised of the following (Figure 13):

- 6 scholarly journal papers
- 3 dissertations and theses
- 8 practitioner conference papers
- 6 academic conference papers

- 1 report

According to the definition in subsection 3.2, 25% of the papers are peer-reviewed literature and 75% of the papers are grey literature.

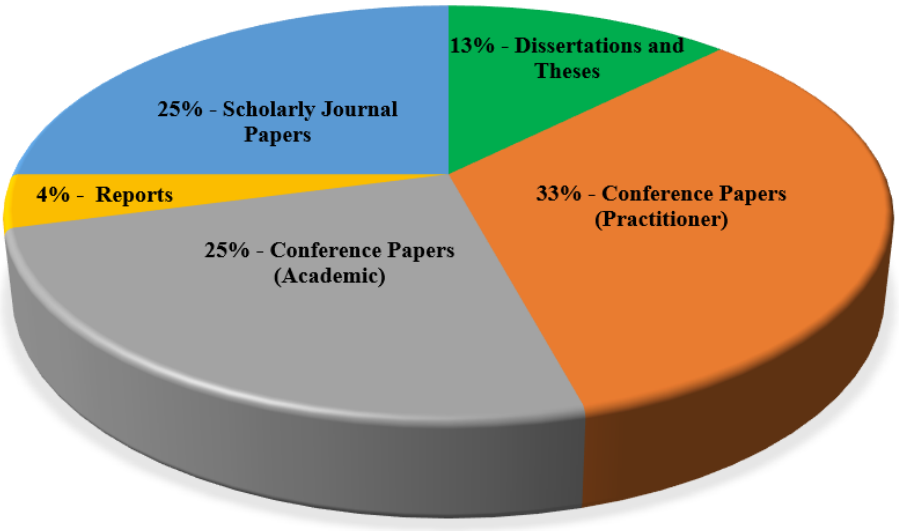


Figure 13: Distribution of review articles by Document Type

As outlined in subsection 3.2, seventeen literature sources were searched. However, the selected review articles were obtained from 10 sources. The majority of the articles were obtained from SAVE International and Research Gate (Figure 14).

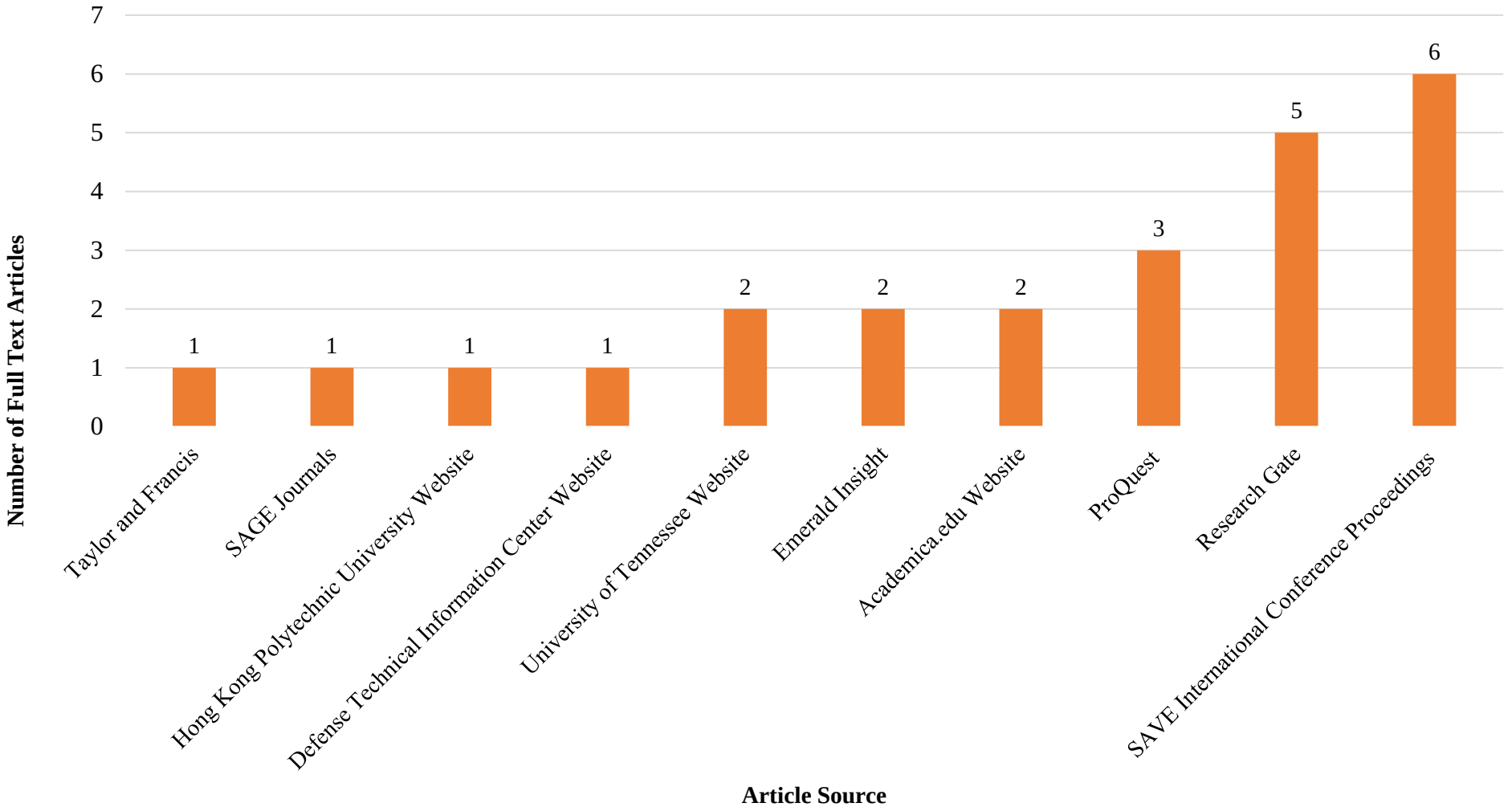


Figure 14: Number of articles obtained from literature sources

In summary, a search strategy that involved the use of 4 search methods and 17 literature sources was applied to ensure that the SLR is expansive and exhaustive. The application of this strategy resulted in the selection of 24 research articles comprised of 5 documents types from 10 literature sources.

4.3 Exploring the Research Quality

The purpose of this section is to discuss the quality of the individual studies by analysing the study design and the critical appraisal results.

All 24 review articles were classified as Qualitative Research. This is because the authors employed data collection methods such as observations, case study methods, interviews, literature review and expert opinion. These studies were further classified according to the research approach. The studies that feature the development and proposal of Lean and VE hybrid methodology were classified as Development Research, and the studies that feature the development and application of Lean and VE hybrid methodology models were classified as Application Research. The majority (63%) of the review articles were classified as Development Research. 37% of the review articles were classified as Application Research (Figure 15), these 9 articles show the application of hybrid models in the following sectors and application areas:

- Manufacturing sector – Design (Chakravartty, 1991)
- Manufacturing sector – Production (Prahladaraj, 2004)
- Manufacturing sector – Production (Nassey, 2004)
- Construction sector – Unspecified (Lehman & Reiser, 2004)
- Public sector (Department of Energy) – Quality Management (Wixson, 2005)
- Product and service sectors – Business Process Re-engineering (Borgianni et al., 2010)
- Manufacturing sector– Design (Sacadura & Tenera, 2011)
- Manufacturing sector – Project Management (Wohnhas, 2014)
- Service sector – Customer Service Centre (Lee et al., 2016)

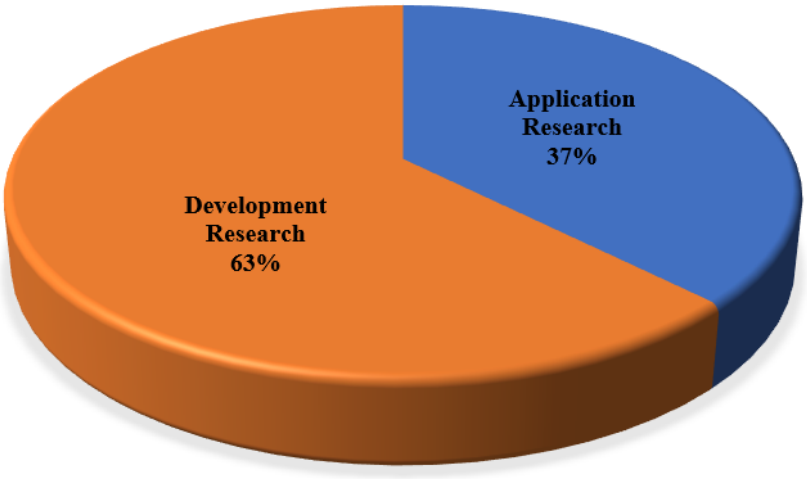


Figure 15: Distribution of review articles by study type

The aim of the critical appraisal process was to evaluate the quality of the review articles based on applicability, validity and reproducibility factors. Each article was assigned a score from 0 to 3 (none to high) for each factor (See Appendix 2 for detailed analysis and scoring), these scores were then converted to percentage scores.

The majority of the review articles have an overall quality score that is 50% and above (Figure 16), however, 2 articles have overall quality scores that are less than 50%. These two articles were written by practitioners (Cell & Arratia, 2003) and an academic (De Hemmer, 2012) and were presented at conferences. The low scores are due to the following:

- No referencing, unspecified data collection methods, low auditability, minimal review of previous literature and the authors did not provide evidence that supports why they propose that "There should be no conflict between Lean and VE" (Cell & Arratia, 2003)
- Inconsistent referencing, minimal review of previous literature, unspecified data collection methods (De Hemmer, 2012)

Six articles (Cell & Arratia, 2003; De Hemmer, 2012; Parker, 2015; Shekari & Fallahian, 2007; Thorsen, 2005; Watson, 2005) scored less than 50% for Validity. These articles are all conference papers. Their low scores are due to the following:

- Unspecified data collection methods
- Minimal review of Lean and VE hybrid methodology literature
- Study limitations were not outlined
- Implications for future research were not outlined
- Biased analysis

Thirteen articles (Cell & Arratia, 2003; De Hemmer, 2012; Ho et al., 2000; Lehman & Reiser, 2004; Nassey, 2004; Nayak, 2006; Parker, 2015; Sacadura & Tenera, 2011; Salvatierra-Garrido et al., 2008; Shekari & Fallahian, 2007; Thorsen, 2005; Watson, 2005; Wohnhas, 2014) scored less than 50% for Reproducibility. The low scores are due to factors such as inconsistent referencing and not specifying research methods, this limits auditability and reproducibility.

Practitioners and academics have different approaches to problem-solving; this is often evident in the level of rigour in research. Similarly, conferences papers and peer-reviewed scholarly journal papers exhibit different levels of rigour. This is evident in the quality scores of the review papers. Nevertheless, all review articles scored above 50% for applicability. Additionally, there is an agreement in Lean and VE hybrid methodology claims, proposals and concepts among all the included review studies.

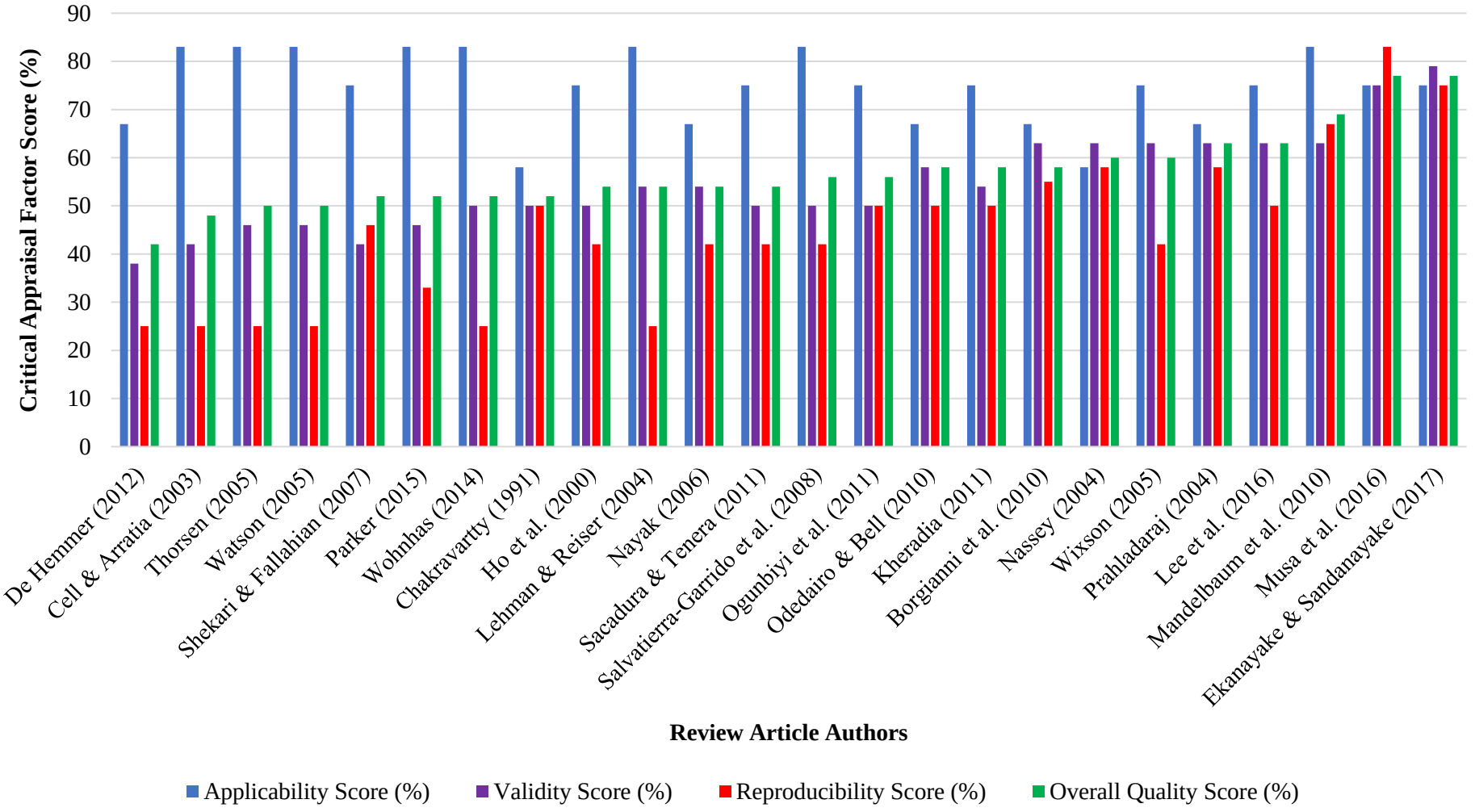


Figure 16: Review article Critical Appraisal results

In summary (section 4), this SLR is based on a sample of 24 articles. These articles all propose the integration of Lean and VE for the purpose of meeting different objectives. It was found that the majority of authors who propose the integration of complete Lean and VE methodologies are practitioners. These practitioners propose complete integration for the purposes of benefitting from the complementary nature of Lean and VE, achieving synergistic benefits and overcoming the weaknesses of the individual methodologies. It was also found that the majority of the authors who propose the integration of components of Lean and VE are academics. These authors propose the integration of components to achieve distinct context-specific objectives.

Exhaustive and expansive research methods were employed in the implementation of the SLRM. These exhaustive and expansive methods resulted in the selection of 24 review articles that consist of 6 document types and were obtained from 10 literature sources. The various document types and literature sources are associated with varying standards of scientific rigour. This is evident in the quality scores that were allocated to the review articles. Despite differences in rigour, all articles have a high level of relevance. This is evident in the agreement observed in the Lean and VE hybrid methodology claims, proposals and concepts (see section 5).

Individual Lean and VE methodologies enjoy multidisciplinary implementation; similarly, the included Lean and VE hybrid methodology research was conducted in various sectors (Manufacturing, Construction, Product and Service, Service and Public sectors) and application areas (Design, Production, Quality Management, Business Process Re-engineering and Customer Service Centres). The majority of the articles simply developed and proposed Lean and VE hybrid models, these articles were classified as Development Research. 37% of the articles included the development and implementation of hybrid models, these articles were classified as Application Research.

5 Data Extraction Results and Analysis

As outlined in Chapter 1, the research questions of this study are the following:

- What variations of Interchangeable, Concurrent and Integrated Use models exist in Lean and VE hybrid methodology literature?
- What guiding principles are evident in the development of Lean and VE hybrid methodology models?
- What model selection framework can be produced from these guiding principles?

The purpose of this section is to present the answers for these research questions by analysing and consolidating the content of the review articles using data extraction and synthesis techniques. This section is organised as follows:

- Section 5.1: An examination of the Lean and VE theoretical concepts and practices that were discussed in the literature review of the sample articles. This section also includes an examination of the Lean and VE theoretical concepts and practices that were utilised to form hybrid models.
- Section 5.2: A review of the proposed and applied Lean and VE hybrid models and their principles.
- Section 5.3: The development and presentation of the proposed hybrid model selection framework.

5.1 Lean and VE Theory & Practices

The purpose of this section is to present and analyse the data extraction results. These results are separated according to two research categories (Development Research and Application Research) to facilitate a comparative analysis of theoretical and empirical Lean and VE hybrid methodology literature. The relevant Lean and VE hybrid methodology research content was extracted using the data extraction checklist discussed in section 3.3.3. The data extraction checklist (Table 7) was applied to extract the following elements from the 24 review articles:

- Lean theory
- Lean practices
- VE theory
- VE practices
- Lean and VE similarity comparison factors
- Lean and VE macro similarities
- Lean and VE micro differences (attached to macro similarities)
- Lean VE difference comparison factors
- Lean and VE differences

- Lean and VE strengths and weakness comparison factors
- Lean and VE strengths and weaknesses
- Lean and VE hybrid models (Interchangeable, Concurrent and Integrated)

Not all authors make use of the hybrid methodology model names that are proposed in this research. However, the models presented by the authors were classified based on three model categories, these models are defined as follows:

- Interchangeable Use models: the employment of either Lean or VE (or their components) in a substitutional manner. Lean and VE are applied separately and are mutually exclusive.
- Concurrent Use models: the simultaneous application of individual Lean and VE (or their components). Lean and VE are applied separately and are mutually inclusive.
- Integrated Use models: the sequenced implementation of amalgamated Lean and VE (or their combined components). Lean and VE connected, interdependent and form a coherent whole. Lean and VE are applied together through a merged structure.

5.1.1 Reviewed Lean Theory and Practices

The first step in the data extraction process involved an examination of the review article introduction and literature review sections. This examination was conducted to extract relevant Lean data to classify the data according to two categories: Lean Theory and Lean Practices (tools and techniques). This analysis was conducted to determine the most common concepts, tools and techniques that were reviewed by the authors. It was also conducted to study homogeneity/heterogeneity between Development and Application Research.

The analysis revealed the following:

- The most commonly reviewed Lean theory and practices in Development Research were (Figure 17 and 18):
    - Theory: Lean Thinking
    - Theory: Waste Identification and Elimination
    - Theory: Toyota Production System and Non-Value Add activities
    - Practice: Value Stream Mapping
    - Practice: Continuous Improvement
    - Practice: Flow Analysis
- However, the most commonly reviewed Lean theory and practices in Application Research were (Figure 17 and 18):
    - Theory: Toyota Production System
    - Theory: Lean History

- Theory: 7 Types of Waste
- Practice: Flow Analysis
- Practice: Pull System
- Practice: Total Quality Management

The practices reviewed in Development Research articles were more extensive than those reviewed in Application Research articles. This is expected because there are a higher number of Development Research papers than Application Research papers. However, the theoretical concepts reviewed in Development Research were less extensive than those reviewed in Application Research. This is unexpected because of the differences in the number of Development and Application Research papers. Additionally, the heterogeneity may be because Development Research often takes a broader view and appraises the most commonly used practices while Application Research takes a narrow view and appraises the most relevant.

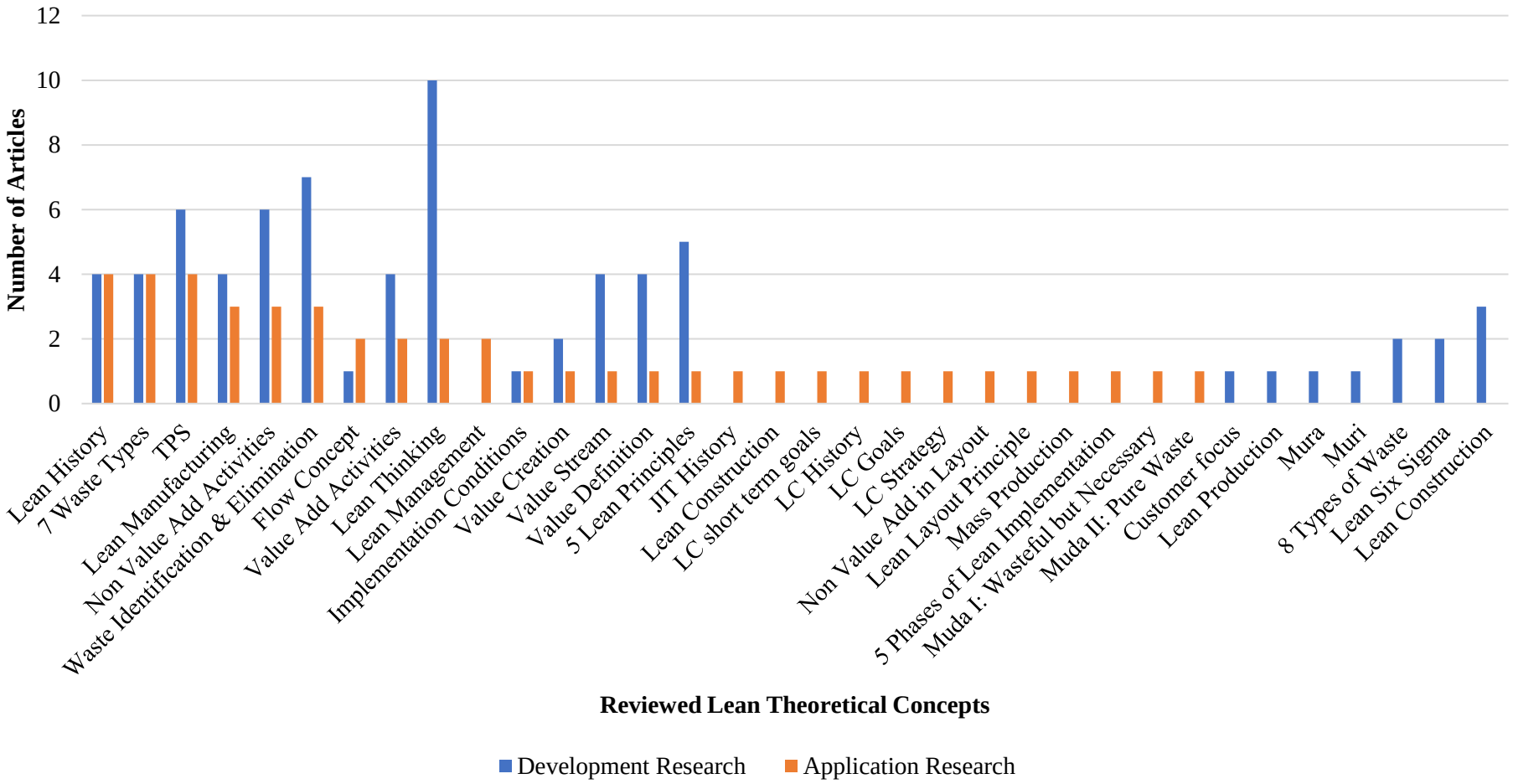


Figure 17: Reviewed Lean Concepts in Lean and VE Hybrid Methodology Literature

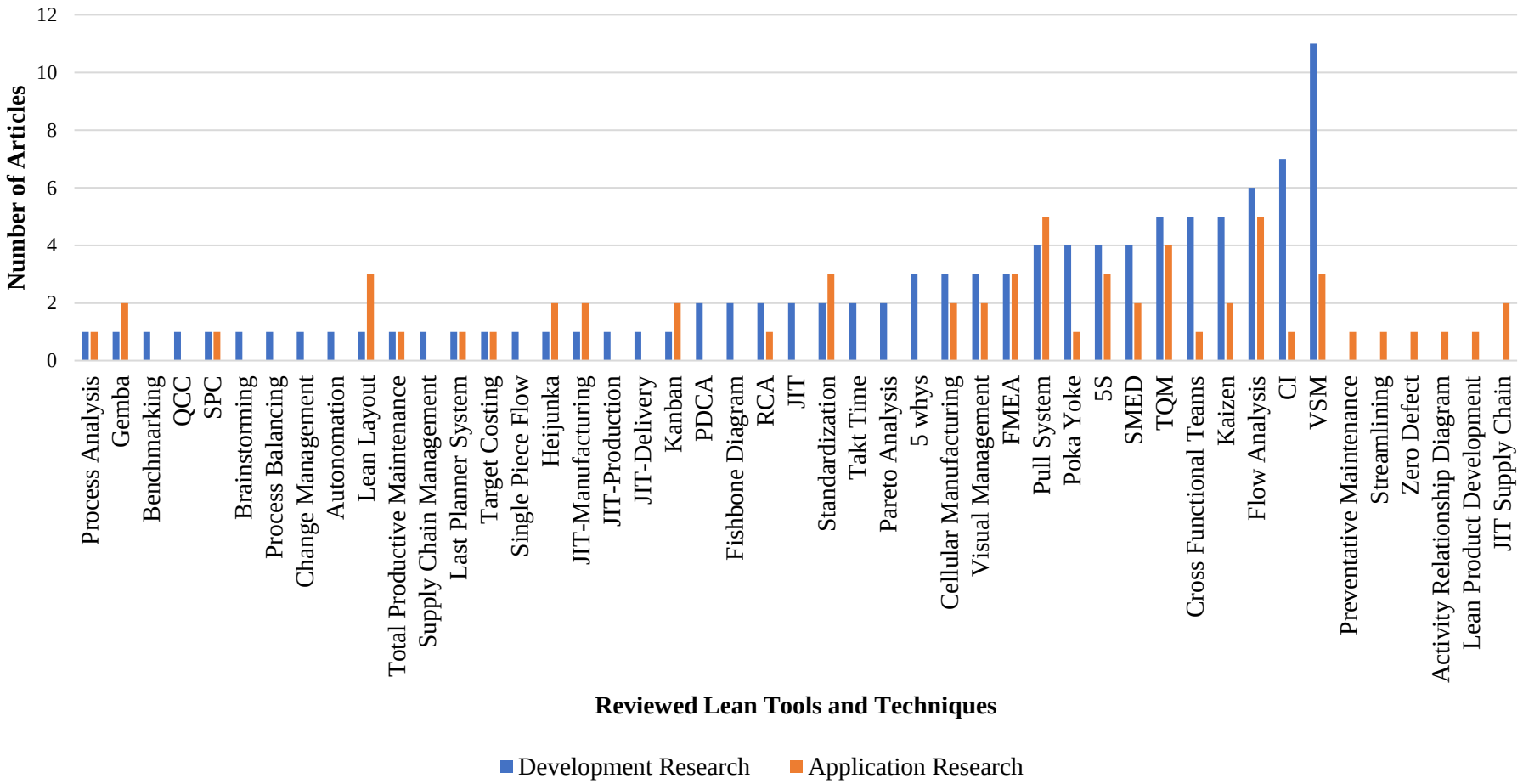


Figure 18: Reviewed Lean Practices in Lean and VE hybrid Methodology Literature

5.1.2 Reviewed VE Theory and Practices

Similar to Lean, an examination of the introduction and literature review of the research papers was conducted to extract relevant VE data to classify the data according to two categories: VE Theory and Practices (tools and techniques). This analysis was conducted to determine the most commonly reviewed concepts, tools and techniques. It was also conducted to study homogeneity/heterogeneity between Development and Application Research.

Contrary to Lean, the analysis revealed the following:

- The most commonly reviewed VE theory and practices in Development Research and Application Research were (Figure 19 and 20):
    - Theory: VE Definition
    - Theory: Value Definition
    - Theory: Function Definition
    - Practice: Function Analysis
    - Practice: FAST Diagram

The practices and theoretical concepts reviewed in Development Research articles were more expansive than those reviewed in Application Research articles. This is expected because there are a higher number of Development Research papers.

Overall, there is homogeneity in the review of VE concepts and practices whether it is for Application or Development Research purposes. However, there is heterogeneity in the review of Lean concepts and practices when Application and Development Research are compared. Moreover, there is also heterogeneity within Application Research and within Development Research because of the ways in which Lean concepts and practices are adapted to sector-specific requirements (e.g. the manufacturing sector applies JIT Manufacturing and the construction sector applies JIT Supply Chain). VE is an analytical technique and thus the observed homogeneity is expected. However, Lean is a lexicon of cultural, management and technical principles/tools/techniques and thus the observed heterogeneity is expected.

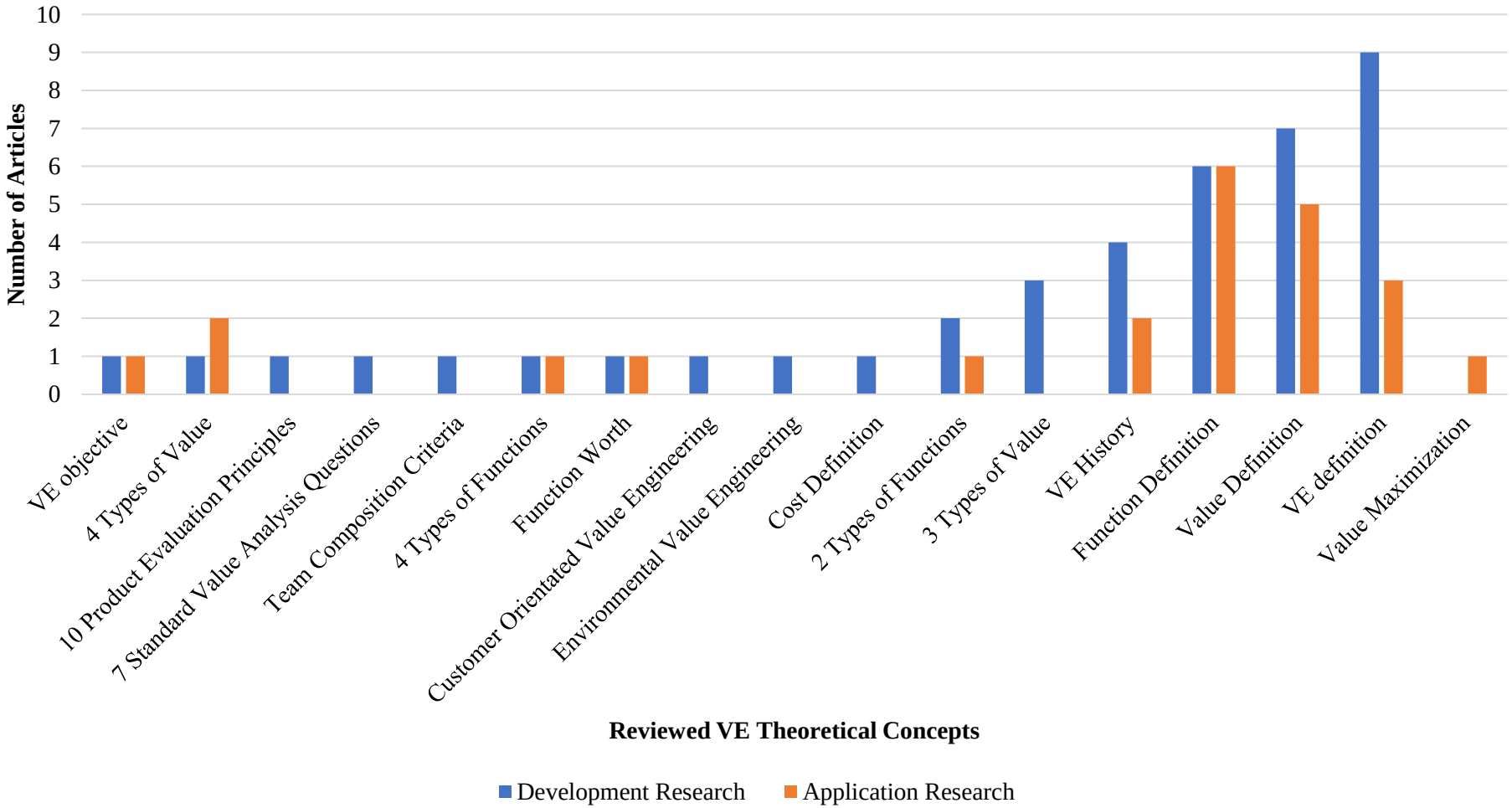


Figure 19: Reviewed VE Theory in Lean and VE Hybrid Methodology Literature

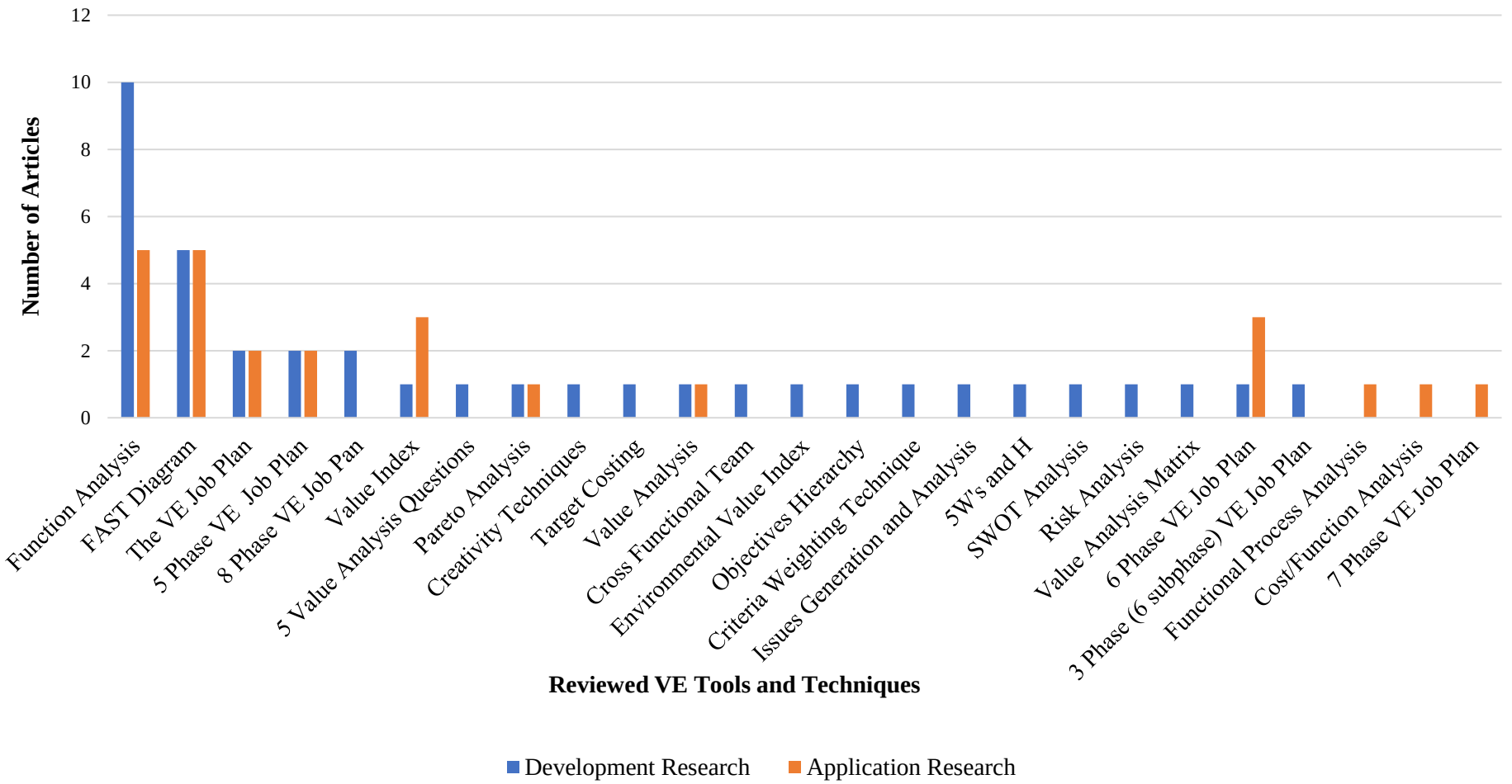


Figure 20: Reviewed VE Practices in Lean and VE Hybrid Methodology Literature

5.1.3 Lean and VE Theory and Practices utilised to form Hybrid Models

Lean and VE were designed separately without intending for their theoretical concepts, tools and techniques to be merged (Nayak, 2006). Therefore, is imperative to analyse the Lean and VE concepts, tools and techniques that are commonly utilised in hybrid models. Additionally, it is vital to compare concepts, tools and techniques that have been *proposed* in Development Research with those that have been successfully *applied* in Application Research. The purpose of this section is to present the results of this analysis.

An analysis of the Lean and VE hybrid methodology models found in the 24 review articles revealed the following:

- The most commonly used Lean concepts, tools and techniques in the hybrid models in Development Research (16 articles) are (Figure 21):
    - VSM
    - Waste Elimination
    - Pull System
- The most commonly used Lean concepts, tools and techniques in the hybrid models in Application Research (9 articles) are (Figure 21):
    - FMEA and Waste Elimination
    - Lean Thinking
    - VSM and Flow Analysis
- The most commonly used VE concepts, tools and techniques in the hybrid models in Development Research (16 articles) are (Figure 22):
    - Function Analysis
    - The VE Job Plan
- The Most commonly used VE concepts, tools and techniques in hybrid models in Application Research (9 articles) are (Figure 22):
    - Function Analysis
    - The VE Job Plan
    - FAST Diagram

Overall, the most commonly used Lean and VE concepts, tools and techniques in the Lean and VE hybrid methodology literature analysed in this study (in both Development and Application Research) are VSM, Waste Elimination, Function Analysis and the VE Job Plan. There is no significant difference between the proposed and applied (Development versus Application Research) VE concepts tools and techniques. However, this is not the case for Lean. VE is an analytical technique and thus the observed homogeneity is expected. However, Lean is a lexicon of cultural, management and technical principles; tools; techniques; and activities and thus the observed heterogeneity is expected.

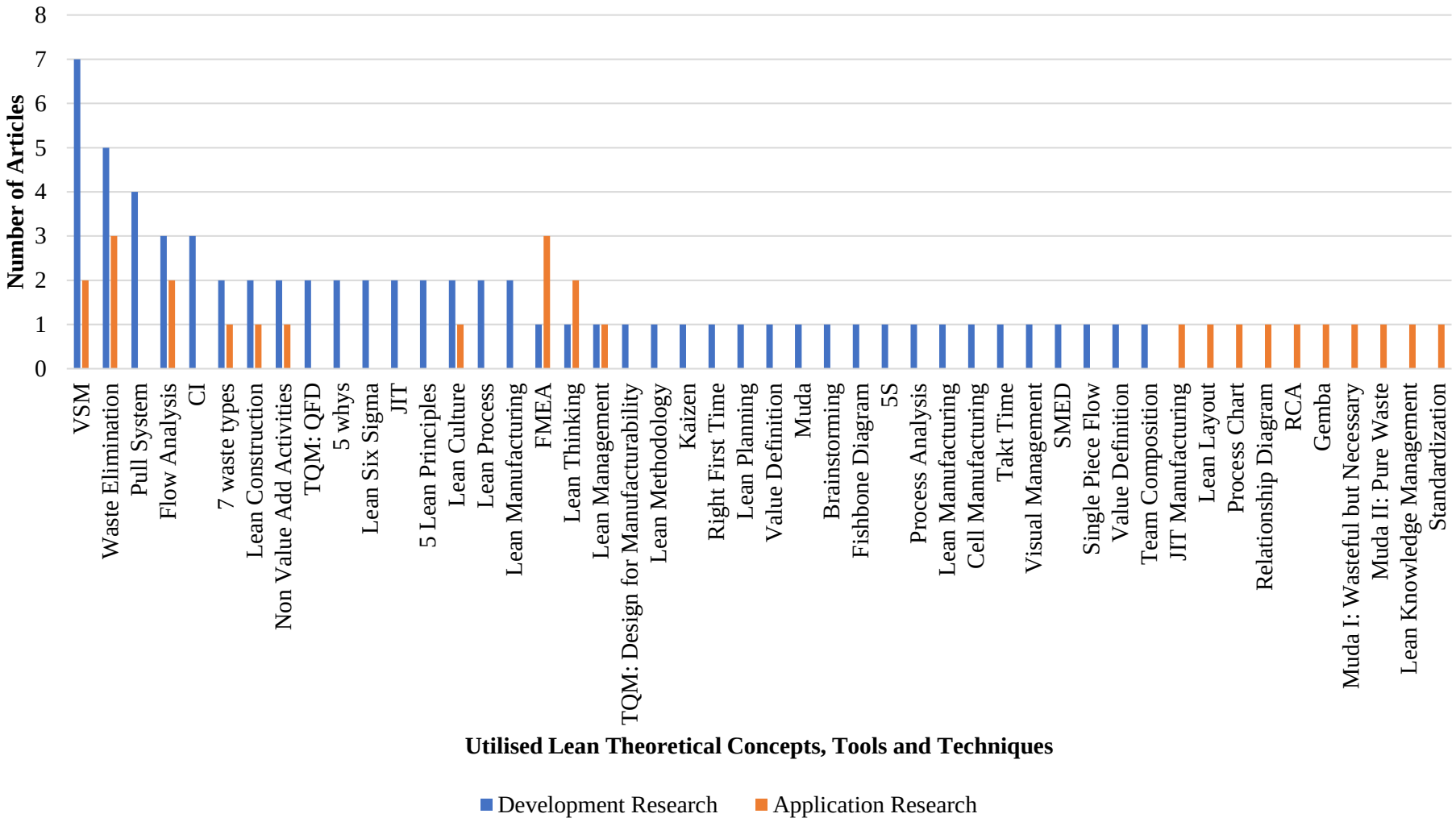


Figure 21: Lean Theory and Practices Utilised to form Hybrid Models

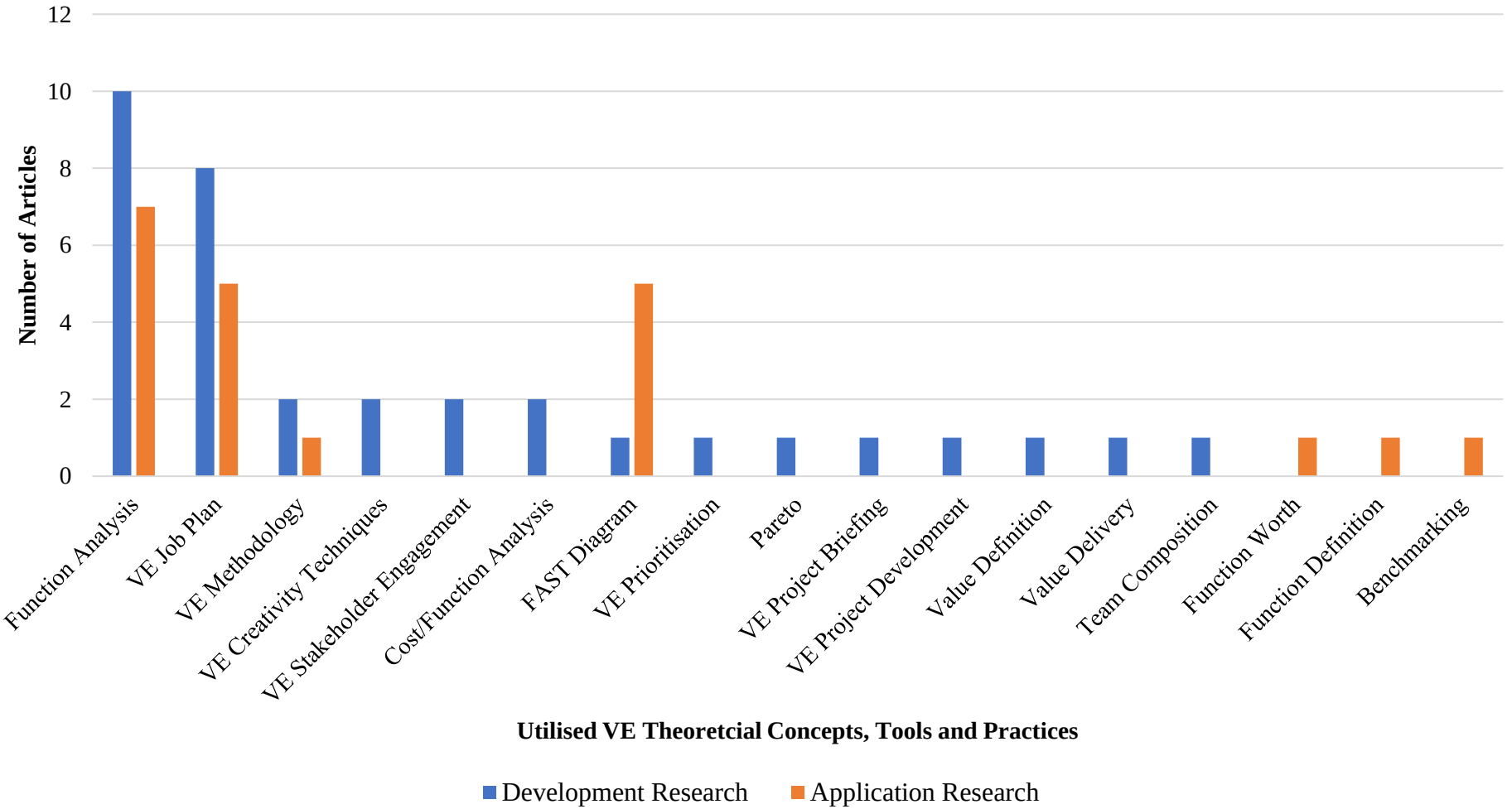


Figure 22: VE Theory and Practices Utilised to form Hybrid Models

5.2 Lean and VE Hybrid Models and Principles

To discover the Lean and VE hybrid methodology models and their principles, the following 5-step approach was applied:

- Arrange the research in chronological order and separate the articles according to Development Research and Application Research categories
- Scrutinise the Lean and VE similarities, differences, strengths and weaknesses that are highlighted by the authors
- Examine the proposed/applied models and classify them as either Interchangeable, Concurrent or Integrated Use models
- Inspect the models to determine whether any other model principles (besides similarities, differences, strengths and weaknesses) are evident in the model development process
- Analyse the relationship between the principles and the models according to the criteria summarised in Table 10 (Nayak, 2006; Shekari & Fallahian, 2007)

Nayak (2006), Shekari & Fallahian (2007) and Cell & Arratia (2003) highlight important elements of Lean and VE hybrid methodology models which are related to Selection, Order, Utilisation and Purpose (SOUP, defined in Table 10). SOUP analysis was utilised to determine the characteristics of Interchangeable, Concurrent and Integrated Use models. The results of this analysis are summarised in the form of findings. The findings are then examined and supplemented with literature to develop a model selection framework.

Table 10: Hybrid Model Characteristics

Hybrid Model Characteristics	**Description**
Selection	Describes the level of model selection: whether it is *strategic* (long term, macro scale, broad and related to organisation mission and plan) or *tactical* (micro-scale, detailed and related to events, procedures and projects)
Order	Details the time aspect of hybrid model implementation: whether the implementation of Lean and VE elements is simultaneous, sequential or substitutional. Additionally, it refers to the arrangement of Lean and VE components and the model structure.
Utilisation	Details application area, project/product/service life cycle phase or application condition in which the model components are applied. It

	also describes the type of problems the components are purposed to solve.
Purpose	Describes the goal of hybrid model formation. The goal can include the following: • Overcome individual methodology weakness • Achieve synergistic benefits • Expand the scope of CI initiatives • Improve the effectiveness of CI Initiatives

5.2.1 Development Research Articles: Hybrid Models and Principles

Article 1: Ho et al. (2000)

The first analysis was applied to the Ho et al. (2000) study. Ho et al. (2000) proposed the integration of VE and TQM. TQM is a management approach that is part of the Lean Lexicon (Lean Enterprise Institute, n.d.). They used an analysis of similarities and differences to generate two Integrated Use and two Concurrent Use models (Table 11). The Selection, Order, Utilisation and Purpose (SOUP) analysis revealed the following:

Selection:

The authors recommended four Tactical Level Integrated Use and Concurrent Use models. These models were intended to guide teamwork, customer focus, and CI events, and procedures.

Finding 1: Concurrent Use models can be selected for Tactical Level initiatives.

Finding 2: Integrated Use models can be selected for Tactical Level initiatives.

Order:

The authors presented all models as *Integrated Models*, however, the analysis conducted in this study revealed that two of the four proposed models should be implemented as *Concurrent Models*. This assessment is described below:

- Ho et al. (2000) proposed Customer Focus Model I as an integrated Model. This model involves the use of TQM: Design for Manufacturability (DFM) to determine design objectives from the manufacturability perspective, and the use of VE to determine design objectives from the function perspective. The authors recommended the *joint* application of these two techniques but did not account for the risk of rework/defect/waiting waste that may be generated if the two components are implemented at different times (sequential/substitutional). Based on this, it would be best to apply DFM and VE simultaneously to minimise the risk of waste generation.

- Similarly, the authors proposed a Teamwork Model that combines VE team formation approaches and TQM team formation approaches. It is best to conduct a simultaneous application of these approaches in a Concurrent Model to ensure that the innovative traits associated with the VE team approach are a constant feature of the TQM team approach.

Finding 3: Concurrent Use models (simultaneous application of Lean and VE concepts, tools and techniques) are recommended when the hybrid initiative requires agreement between Lean and VE outputs. This is to avoid output misalignment and rework. Rework is a result of defect waste, and rework can create *waiting* waste.

The two proposed Integrated Use models involved 3/4 sequenced steps. VE is implemented before Lean in both models because it VE is first used to identify and evaluate customer functional desires to ensure that subsequent design and CI activities are directed by the functional requirements of the customer.

Finding 4: Integrated Model development: VE can be implemented before Lean to ensure that subsequent steps are directed by customer function requirements.

Utilisation

The proposed Integrated and Concurrent Use models involve the use of Lean and VE in the same application areas (design and CI).

Finding 5: Integrated Use models can involve the sequential utilisation of Lean and VE components in the same application area.

Finding 6: Concurrent Use models can involve the simultaneous utilisation of Lean and VE components in the same application area.

Purpose:

Ho et al. (2000) proposed Integrated and Concurrent Use Models to achieve effective customer satisfaction by combining VE with TQM.

Finding 7: Integrated Use hybrid models can be purposed to improve the effectiveness of individual Lean and VE initiatives.

Finding 8: Concurrent Use models can be purposed to improve the effectiveness of individual Lean and VE initiatives.

Table 11: Ho et al. (2000) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Objective **Macro Similarities:** 1.1. Customer focus 1.2. Elimination of non-value add 1.3. Team Dynamics **Micro Difference:** 1.1. Lean Waste & VE Function Perspective 1.2. Value Definition 1.3. Team language	**Comparison Factor:** 1. Analytical Approach **Difference:** 1.1. Lean: Quality 1.2. VE: Function **Comparison Factor:** 2. Communication Tool **Difference:** 2.1. Lean: TQM Survey/ QFD 2.2. VE: Function Analysis **Comparison Factor:** 3. Team Formation Time **Difference:** 3.1. Lean: Once off 3.2. VE: Ad Hoc **Comparison Factor:** 4. CI Focus **Difference:** 4.1. Lean: Product/Process Quality 4.2. VE: Product/Process Function	**Concurrent Use Models:** <u>Customer Focus Model I:</u> Design: Apply TQM Design for Manufacturability to determine design objectives Design: Joint application of VE to determine function design objectives <u>Teamwork Model:</u> VE ad hoc Team approach combined with Lean TQM team approach **Integrated Use Models:** <u>Customer Focus Model II</u> **Step 1:** VE: Identify/Evaluate new or existing functions **Step 2:** VE & TQM: Evaluate Cost of required Quality and Functions **Step 3:** Review: Evaluate Cost/Function/Quality Suitability (if not approved customer return to step 1) **Step 4:** QFD: Translate Quality/Function requirements to Technical Product Specifications <u>CI Model</u> **Step 1:** VE: Identify unnecessary and important functions/ Review customer functional requirement changes over time **Step 2:** VE: List all essential functions to guide CI activities **Step 3:** CI: Conduct priority improvements based on essential functions

Article 2: Cell & Arratia (2003)

The second analysis was applied to the Cell & Arratia (2003) study. The authors proposed a complete integration of Lean and VE. They utilised an assessment of Lean and VE strengths, weaknesses, similarities and differences to develop four Integrated Use models (Table 12). The SOUP analysis revealed the following:

Selection:

The authors recommended three tactical level Integrated Use models (VSM, Kaizen and the VE Job Plan models), this supports that Integrated Use models can be selected for tactical level initiatives **(Finding 2)**. The authors also proposed an operational model, this model is a strategic level initiative because it is recommended for the operational strategy of an organisation.

Finding 9: Integrated Use models can be selected for strategic level initiatives.

Order:

Cell & Arratia (2003) proposed two models (VSM and operational models) that involve initial Lean implementation to create opportunities for subsequent VE implementation.

Finding 10: Integrated Use model development can involve the following Lean and VE arrangement: Lean initiatives are applied first to create opportunities for the subsequent implementation of VE.

Furthermore, the authors endorsed a VE Job Plan model (Integrated Use model) that involves the addition of a Lean component (7 types of Waste analysis) to a sequenced and unaltered VE procedure. Similarly, the authors proposed a Kaizen model (Integrated Use model) that includes the addition of VE components (Functions Analysis and Job Plan) to a sequenced and unaltered Lean procedure (Cellular Manufacturing).

Finding 11: The development of an Integrated Use model can involve the addition of Lean components to a sequenced and unaltered VE practice or the addition of VE components to a sequenced and unaltered Lean practice.

Utilisation:

The authors did not provide sufficient information that allows readers to concluded whether Lean and VE components are utilised in similar or dissimilar application areas in the VSM, Operations and VE Job Plan models. However, Lean and VE are applied to the same application area (manufacturing cell) in the Kaizen model, this supports that Integrated Use models can involve the sequential utilisation of Lean and VE components in the same application area **(Finding 5)**.

Purpose:

Cell & Arratia (2003) proposed three Integrated Use models (Kaizen, VE Job Plan and Operational models) that were purposed to overcome Lean and VE weaknesses. Additionally, the authors proposed the VSM model to expand the scope of VSM to product redesign and modification.

Finding 12: Integrated Use models can be developed for the purpose of overcoming the weaknesses of individual Lean and VE methodologies

Finding 13: Integrated Use models can be developed to expand the scope of individual Lean and VE methodologies.

Table 12: Cell & Arratia (2003) hybrid models and principles

Similarity Items	Difference Items	Strength & Weakness Items	Models
Comparison Factor: 1. Approach **Macro Similarity:** 1.1. Customer focus and teamwork **Micro Difference:** 1.1. Customer Value definition and team language **Comparison Factor:** 2. Tools **Macro Similarity:** 1.1. Visual Tools **Micro Difference:** 1.2. Lean VSM and VE FAST tools **Comparison Factor:** 3. People **Macro Similarity:** 3.1. Provide Operator Support **Micro Difference** 3.2. Lean empowers operators VE includes operators in the workshop	**Comparison Factor:** 1. Approach **Difference:** 1.1 Lean: Organisation Transformation 1.2 VE: Analytical Technique **Comparison Factor:** 2. Application Area **Difference:** 2.1. Lean: High Volume Process 2.2. VE: All Process Types **Comparison Factor:** 3. Implementation Time **Difference:** 3.1. Lean: Long term, iterative and ongoing 3.2. VE: Short term and episodic **Comparison Factor:** 4. Implementation Area **Difference:** 4.1. Lean: Product Maturity Stage 4.2. VE: Product Design Stage	**Comparison Factor:** 1. Scope **Strength & Weakness:** 1.1. Lean Strength: Lexicon of philosophies/tools/techniques that influence Strategy. Holistic Operational Philosophy. 1.2. VE Weakness: Analytical techniques that influence Isolated study events. **Comparison Factor:** 2. Tools **Strength & Weakness:** 2.1. Lean Weakness: No systematic tools to explore functional/work relationship in a work area. No systematic technique to create a Lean cell. 2.2. VE Weakness: Waste elimination is not a distinct activity	**Integrated Use Models:** VSM Model **Step 1:** Application of VSM **Result 1:** VSM Recommendations include product redesign and equipment modification **Step 2:** Application of VE to redesign the product and modify the equipment Operational Model **Step 1:** Implement Lean as an operational strategy to create a Lean culture and create waste/value/cost awareness. **Result 1:** Organisation develops opportunities for VE implementation **Step 2:** Implement VE to reduce costs, eliminate waste and increase value Kaizen Model **Day 1:** Define Conditions **Day 2:** Create Lean Cell (Apply VE Functional Analysis and Creativity Techniques **Day 3:** Run/Test/Improve Cell (Integrate VE Job Plan) **Day 4:** Standardization **Day 5:** Review The VE Job Plan Model **Step 1:** Information gathering **Step 2:** Functional Analysis and Lean 7 Waste types Analysis **Step 3:** Speculation/Creativity **Step 4:** Development **Step 5:** Evaluation **Step 6:** Presentation

Article 3: Thorsen (2005)

The third analysis was applied to the Thorsen (2005) study. The author proposed a complete integration of VSM and VE. He utilised an assessment of Lean and VE similarities and differences to recommend combining VSM and VE (Table 13). However, the author did not propose a specific model that allows for SOUP analysis.

Table 13: Thorsen (2005) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Tools **Macro Similarities:** 1.1. VSM "Define Value" Phase and VE "Pre-study" Phases both determine evaluation factors and scope of the study 1.2. VSM "Determine Current State Map" and VE "Functional Analysis" Phases both analyse features and performance 1.3. VSM "Create Future State Map" and VE "Creativity and Evaluation" Phases both generate an implementation plan 1.4. VSM "Implementation Plan" and VE "Development and Recommendation" Phases both create and implement an effective improvement plan. 1.5. VSM "Process Improvement" and VE "Post Study" Phases both monitor the progress of results **Micro Difference:** 1.1. VE: Value if not defined in the Pre-study Phase, it is defined in the Function Analysis Phase 1.2. Current State focus is on flow and time; VE focus is on functions 1.3. Future State Map creation does not involve the distinct Creativity Techniques that the VE Creativity Phase involves. 1.4. VSM plan seeks to minimise waste while the VE plan is intended for function provision 1.5. VSM Improvement is based on iterative Continuous Improvement principles and VE utilises auditing techniques. **Comparison Factor:** 2. Goal **Macro Similarity:** 2.1. Building Customer Value **Micro Difference** 2.2. Lean value build is done through Waste Elimination and VE is done through function provision **Comparison Factor:** 3. Focus **Macro Similarity:** 3.1. Customer and team-based process **Micro Difference** 3.2. Lean: customer focus- value and waste perspective, VE: customer focus- value and function perspective.	**Comparison Factor:** 1. Application Area **Difference:** 1.1. Lean: Process or Procedure 1.2. VE: Process, Product or Service **Comparison Factor:** 2. Goal **Difference:** 2.1. Lean: Increase Process flow 2.2. VE: Improve function and reduce life cycle cost	The author did not provide a specific model type. The author proposed that VSM complements VE because of similarities. He proposes that VSM and VE similarities result in a natural synergy between VSM and VE.

Article 4: Watson (2005)

The fourth analysis was applied to the Watson (2005) study. The author proposed a complete integration of Lean and VE. He utilised an assessment of Lean and VE differences to justify the proposal of two Integrated Use models (Table 14). The SOUP analysis exposed the following:

Selection:

Watson (2005) recommended one tactical level Integrated Use model (the VE Job Plan model), this confirms that Integrated Use models can be selected for tactical level initiatives **(Finding 2)**. The author also proposed a Lean Management Philosophy model, this model is a strategic level initiative because it is a broad plan intended to guide the management of an organisation, this supports that Integrated Use models can be selected for strategic level initiatives **(Finding 9)**.

Order:

The author suggested a VE Job Plan model (Integrated Use model) that includes the addition of a Lean component (5 whys) to a sequenced and unaltered VE procedure, this supports that the development of an Integrated Use model can involve the addition of a Lean component to a sequenced and unaltered VE practice **(Finding 11)**. Similarly, the author recommended a Lean Management Philosophy (Integrated Use model) that includes the addition of a VE component (Functional Analysis) to a sequenced and unaltered Lean practice **(Finding 11)**.

Utilisation:

The author did not provide sufficient information regarding model application areas; therefore, no interpretations were made.

Purpose:

Watson (2005) infused a Lean component into the VE Job Plan to expand the scope of the VE Job Plan. Similarly, he infused a VE component into the Lean Management Philosophy to expand the scope of the philosophy. This supports that Integrated Use models can be developed to expand the scope of CI initiatives **(Finding 13).**

Table 14: Watson (2005) hybrid models and principles

Difference Items	**Models**
Comparison Factor: 1. Focus **Difference:** 1.1. Lean: Waste 1.2. VE: Function **Comparison Factor:** 2. Approach **Difference:** 2.1. Lean: Waste/Root Cause Analysis 2.2. VE: Function/Cost Analysis **Comparison Factor:** 3. Goal **Difference:** 3.1. Lean: Eliminate the process-related cost 3.2. VE: Eliminate function related cost	**Integrated Use Model:** VE Job Plan Model **Step 1:** Information gathering **Step 2:** Functional Analysis and Lean Five Whys (determine Root Cause) **Step 3:** Speculation/Creativity **Step 4:** Development **Step 5:** Evaluation **Step 6:** Presentation Lean Management Philosophy **Step 1:** Lean Value definition based on Customer wants **Step 2:** Value Delivery process design **Step 3:** Value Development and tracking to ensure value delivery **Step 4**: Function Analysis **Step 5:** Value addition to the product by the process **Step 6:** Right First-Time production **Step 7:** Lean Elimination of unnecessary activity and VE elimination of unnecessary function.

Article 5: Nayak (2006)

The fifth analysis was applied to the Nayak (2006) study. The author proposed a complete integration of Lean and VE. He utilised an assessment of Lean and VE similarities, differences, strengths and weaknesses to justify the proposal of one Integrated Use model (Table 15). The SOUP analysis showed the following:

Selection:

Nayak (2006) recommended one tactical level Integrated Use model (the VSM model), this supports that Integrated Use models can be selected for tactical level initiatives **(Finding 2)**.

Order:

The author proposed an Integrated Use model (the VSM model) that involves initial Lean implementation (VSM) to first identify areas of waste and high cost and create opportunities for VE implementation. This supports that Integrated Use models can involve the implementation of Lean prior to VE to create opportunities for subsequent VE implementation **(Finding 10)**. Furthermore, the proposed model features the addition of VE components to a sequenced and unaltered Lean practice (VSM), supporting **Finding 11**.

Utilisation:

The author did not provide sufficient information regarding model application areas; therefore, no interpretations were made.

Purpose:

Nayak (2006) proposed that the advantages of respective Lean and VE strengths can be combined in order to realise synergistic benefits. He provided an example of such a model: An Integrated Use model that involves a sequenced and interdependent Lean VSM and VE combination. Synergy can only be achieved when two interdependent components interact and that interaction produces a combined effect. Lean and VE are not interdependent and do not interact in Interchangeable and Concurrent Use models, Lean and VE only interact in Integrated Use models. Therefore, the synergistic benefits of Lean and VE can only be produced by Integrated Use models.

Finding 14: Integrated Use models are the only type of Lean and VE hybrid model that can be developed for the purpose of realising Lean and VE synergistic benefits.

Table 15: Nayak (2006) hybrid models and principles

Similarity Items	Difference Items	Strength & Weakness Items	Models
Comparison Factor: 1. Strategic Goals **Macro Similarity:** 1.1. Value Building, Cost/Waste Reduction and Quality Improvement **Micro Difference:** 1.2. Goals achieved from different perspectives- Lean: Waste perspective & VE: function perspective **Comparison Factor:** 2. Approach **Macro Similarity:** 2.1. Teamwork, Systematic, Cost/Performance balance **Micro Difference:** 2.2. Team language, VE Job Plan/5 Lean principles, VE: Cost/Function balance/Lean: Cost of Waste **Comparison Factor:** 3. Focus **Macro Similarity:** 3.1. Customer **Micro Difference** 3.2. Lean: eliminate non-value adding activities, VE: provide customer functional requirements	**Comparison Factor:** 1. Application Area **Difference:** 1.1. Lean: Process and Service 1.2. VE: Design and Construction **Comparison Factor:** 2. Focus **Difference:** 2.1. Lean: Non-Value Add Activities 2.2. VE: Non-Value add product/process/system features **Comparison Factor:** 3. Cost Reduction **Difference:** 3.1. Lean: Labour and Overhead cost 3.2. VE: Material Cost **Comparison Factor:** 4. Visual Analytical Tool **Difference:** 4.1. Lean: VSM: the flow of material and information 4.2. VE: FAST: Function interrelationships **Comparison Factor:** 5. Scope **Difference:** 5.1. Lean: Principles/Attitudes/Practices 5.2. VE: Analytical tools	**Comparison Factor:** 1. Approach **Strength:** 1.1. Lean Strength: Systematic Enterprise Approach, High Enterprise Transformation 1.2. VE Strength: Risk Management/Design & Creativity Tools, Effective with incomplete data **Comparison Factor:** 2. Approach **Weakness:** 2.1. Lean Weakness: No Design and Creativity tools VE Weakness: Subjective and time-consuming team approach, high human resource utilisation **Comparison Factor:** 3. Cost **Strength & Weakness:** 3.1. Lean Weakness: High Entry Cost 3.2. VE Strength: Low Entry Cost	**Integrated Model:** VSM Model **Step 1:** Process Selection based on Goals/High Cost/Problem **Step 2:** Develop Current State Map **Step 3:** Develop Future State Map **Step 4:** Develop Future State Plan: Do it actions, Action Targeting by choosing either Lean Manufacturing or VE methods, Change Implementation Actions, Upstream and Downstream CI/VSM events

Article 6: Shekari & Fallahian (2007)

The sixth analysis was applied to the Shekari & Fallahian (2007) study. The authors proposed the integration of a few VE components with Lean Management. They utilised an assessment of Lean and VE similarities and differences to justify the proposal of a 20-step Integrated Use model (Table 16). The SOUP analysis findings are as follows:

Selection:

Shekari & Fallahian (2007) recommended a 20-step model that combines strategic level components (Lean Management Philosophy and Continuous Improvement) with tactical level components (Lean VSM, Muda Elimination, VE Function Analysis and VE prioritisation tools). The proposed Integrated Use model is a hybrid of strategic and tactical level initiatives.

Finding 15: Integrated Use models can be selected for a combination of strategic and tactical level initiatives.

Order:

The authors proposed an Integrated Use Model where Lean is applied before VE implementation. Shekari & Fallahian (2007) argued that it is best to implement Lean first because the first step in Lean implementation is value definition.

Finding 16: Integrated Use model development: Lean components are implemented before VE components to ensure that the first model step involves value definition.

Furthermore, they argued that Lean training and a Lean culture create an environment in which VE can be easily/successfully applied.

Finding 17: Integrated Use model: Lean initiatives can be applied first to create an environment/culture where VE can be easily/successfully applied.

Shekari & Fallahian (2007) claimed that implementing VE first does not create a Lean friendly environment instead it creates an environment where VE and Lean will contradict each other, however, the authors did not provide sufficient evidence to support this claim.

Utilisation:

Shekari & Fallahian (2007) pointed out that Lean and VE are often implemented in different application areas. Lean is applied to improve production and processes and VE is applied to improve products. They argued that their Integrated Use model results in improvement within two application areas (process and product value) which meets both the company and customer requirements.

Finding 18: Integrated Use models can involve the sequential implementation of Lean and VE in dissimilar application areas.

Purpose:

Similar to Nayak (2006), Shekari and Fallahian (2007) argued that their Integrated Use model results in synergy when Lean and VE strengths are combined. This supports that Integrated Use models are the only type of Lean and VE hybrid model that can be developed for the purpose of realising Lean and VE synergistic benefits **(Finding 14)**.

Table 16: Shekari & Fallahian (2007) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. History **Macro Similarities:** 1.1. Manufacturing **Micro Difference:** 1.2. Lean: Toyota for production purposes. VE: General Electric for procurement purposes. **Comparison Factor:** 2. Key Success Factors **Macro Similarities:** 2.1. Management Involvement, Team approach, Planning and training **Micro Difference:** 2.2. Lean and VE have different training and planning practices. **Comparison Factor:** 3. Benefits **Macro Similarities:** 3.1. Cost Reduction and Value Increase **Micro Difference:** 3.2. VE and Lean have different value definitions. They reduce cost from function (VE) and waste (Lean) perspectives.	**Comparison Factor:** 1. Aim **Difference:** 1.1. Lean: Establish Value Stream: Eliminate Waste 1.2. VE: Cost Reduction; Profit/Quality Improvement **Comparison Factor:** 2. Methodology **Difference:** 2.1. Lean: Semi-structured: Waste identification & elimination 2.2. VE: Effective & efficient analysis project: Function Analysis **Comparison Factor:** 3. Application Area **Difference:** 3.1. Lean: Production, Maintenance, Human Resource, Quality 3.2. VE: Design, Planning, Hard/Software, Procurement, Functionality, Maintenance **Comparison Factor:** 4. Assumption **Difference:** 4.1. Lean: Waste Elimination will lead to improvements; small incremental change better than big episodic change 4.2. VE: Surplus Functions Exist **Comparison Factor:** 5. Limitations **Difference:** 5.1. Lean: Lack of prioritisation tools 5.2. VE: No improvement continuity, fails to recognise all activities, no integration of method and culture	**Integrated Model:** **Step 1:** Slogan **Step 2:** Management Goals and Policies **Step 3:** Project Planning **Step 4:** Setting Borders **Step 5:** Determine Value **Step 6:** Function Analysis **Step 7:** Idea making (Brainstorming) **Step 8:** Presenting Improvement **Step 9:** Assessment Prioritisation (VE methods) **Step 10:** Idea Selection **Step 11:** Sketch the Value Stream **Step 12:** Muda **Step 13:** Brainstorming **Step 14:** Cost Analysis **Step 15:** Identify Non-Value Add/ Choosing for Muda **Step 16:** Present Alternative/ Prioritisation Planning for Muda Elimination **Step 17:** Corrective Activities **Step 18:** Pull System **Step 19:** Continuous Improvement **Step 20:** Pursue Perfection

	Comparison Factor: 6. Initial Results **Difference:** 6.1. Lean: Reduced Process Time 6.2. VE: Reduction in Total time whilst maintaining require functions **Comparison Factor:** 7. Project Selection Criteria Difference: 7.1. Lean: High Waste/Low Profitability/Low Flexibility/Low Efficiency 7.2. VE: High Cost/High Complexity/Multi-disciplinary project/Budget and Time limitations	

Article 7: Salvatierra-Garrido et al. (2008)

The seventh analysis was applied to the Salvatierra-Garrido et al. (2008) study. The authors proposed the integration of complete Lean with a component of VE. They analysed Lean and VE differences to justify combining Lean Thinking and VE Stakeholder Management (Table 17). However, the authors did not propose a model that allows for SOUP analysis.

Table 17: Salvatierra-Garrido et al. (2008) hybrid models and principles

Difference Items	**Models**
Comparison Factor: 1. Application Time **Difference:** 1.1. Lean: Production/Construction Stage of Project Life Cycle 1.2. VE: Conceptual/Project Briefing Stage **Comparison Factor:** 2. Aim **Difference:** 2.1. Lean: Flow Improvement 2.2. VE: Function Analysis **Comparison Factor:** 3. Value Approach **Difference:** 3.1. Lean: Initial step: Value Identification/ Value Stream Definition 3.2. VE: Cost/Function/Quality Relationship **Comparison Factor:** 4. Project Briefing Approach **Difference:** 4.1. Lean: None 4.2. VE: Interactive Workshops/Stakeholder Participation in Concept & Design	The authors did not provide a specific model type. They recommended combining Lean and VE approaches in Project Briefing to improve stakeholder engagement. Project Briefing Recommendations **Item 1:** Guideline Provision **Item 2:** Systematization of activities (Lean Thinking/ Process Optimisation/ Flow Creation) **Item 3:** Link Generation (current and future users) **Item 4:** Satisfaction Survey **Item 5:** Early Stage Stakeholder Engagement (VE Value Workshop Approach) **Item 6:** Provide Information to Stakeholders **Item 7:** Include Formal Tools & Procedures Early project Stage (VE Approach to collect user needs)

Article 8: Mandelbaum et al. (2010)

The eighth analysis was applied to the Mandelbaum et al. (2010) study. The authors proposed the integration of Lean Six Sigma and VE. They utilised an assessment of Lean and VE similarities and differences to justify the proposal of a Lean Six Sigma Integrated Use model (Table 18). The authors also proposed combining Lean and VE within the Product/Service/Construction Project life cycle processes, however, this proposal does not that allow for SOUP analysis. Furthermore, the authors proposed the integration of Six Sigma tools and VE through the VE Job Plan (Integrated Use) model, this is not included in the SOUP analysis because it does not involve the use of Lean tools. The SOUP analysis of the Lean Six Sigma Integrated Use model revealed the following:

Selection:

The proposed Lean Six Sigma (Integrated Use) model combines tactical level Lean Six Sigma components (e.g. DMAIC, 5S, 5whys) with VE tactical level components (Function Analysis and creativity techniques). This supports that Integrated Use models can be selected for tactical level initiatives **(Finding 2).**

Order:

The authors suggested a Lean Six Sigma (Integrated Use) model that includes the addition of VE components (Function Analysis and creativity techniques) to a sequenced and unaltered Lean Six Sigma procedure.

Finding 19: The development of an Integrated Use model can involve the addition of VE components to a sequenced and unaltered Lean Six Sigma practice.

Utilisation:

The author did not provide sufficient information regarding model application areas; therefore, no interpretations were made.

Purpose:

Similar to Nayak (2006) and Shekari and Fallahian (2007), the authors combined a Lean Six Sigma strength and a VE strength to create a model that results in synergy. This supports that Integrated Use models are the only type of Lean and VE hybrid model that can be developed for the purpose of realising synergistic benefits **(Finding 14)**.

Table 18: Mandelbaum et al. (2010) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Focus **Macro Similarities:** 1.1. Customer and Value **Micro Difference:** 1.2. Lean Waste & VE Function Perspective	**Comparison Factor:** 1. Solution **Difference:** 1.1. Lean: Waste Elimination 1.2. VE: Function/Cost Analysis **Comparison Factor:** 2. Recommendations **Difference:** 2.1. Lean: Based on Root Cause 2.2. VE: Based on Function **Comparison Factor:** 3. Creativity **Difference:** 3.1. Lean: Brainstorming to fix Root Cause 3.2. VE: Brainstorming to find alternatives and to innovate **Comparison Factor:** 4. Evaluation **Difference:** 4.1. Lean: Prioritisation of waste eliminating solutions 4.2. VE: Prioritisation based on feasibility and function requirements **Comparison Factor:** 5. Application Area **Difference:** 5.1. Lean: Existing products and services 5.2. VE: Product and Process Design	**Integrated Model:** The Life Cycle Model: Integration of Lean Six Sigma and VE in the Product/Service/Construction Project Life cycle processes. VE Job Plan Model: **Step 1:** Information Phase): Integrate formal Lean Six Sigma LSS) Data collection methods – Likert, Surveys, interviews, focus groups **Step 2:** Function Analysis Phase: Integrate LSS SIPOC (Supplier, Inputs, Process, Outputs, Customers) Analysis **Step 3:** Creativity Phase **Step 4:** Evaluation Phase **Step 5:** Development Phase **Step 6:** Presentation/Implementation Phase: Integrate LSS formalised corrective action activities and Control Phase activities. Lean Six Sigma Model **Step 1:** Define **Step 2:** Measure **Step 3:** Analyse: Lean RCA/5 whys/Fishbone/FMEA integrated with VE: Function Analysis **Step 4:** Improve: Lean Waste elimination/5S/JIT/Pull System integrated with VE Creativity Techniques Evaluation and Development Techniques: Life Cycle cost and Feasibility Analysis **Step 5:** Control

	Comparison Factor: 6. Cost Reduction Area **Difference:** 6.1. Lean: Labour and Overhead Costs 6.2. VE: Design and Material Costs **Comparison Factor:** 7. Results **Difference:** 7.1. Lean: Incremental Cost Reduction (Long Term) 7.2. VE: Cost Reduction in the Short Term **Comparison Factor:** 8. Goal **Difference:** 8.1. Lean: Waste Elimination 8.2. VE: Life Cycle Cost Reduction/ Improved Investment Returns **Comparison Factor:** 9. Focus **Difference:** 9.1. Lean: Holistic Enterprise: Process and People 9.2. VE: Function/Worth Analysis **Comparison Factor:**	

Article 9: Odedairo & Bell (2010)

The ninth analysis was applied to the Odedairo & Bell (2010) study. The authors proposed the integration of Lean components (VSM and TQM: QFD) with the VE Job Plan. They briefly highlighted the strengths and weaknesses of VE (Table 19) to rationalise the proposal of one Integrated Use model (The VE Job Plan model). The SOUP analysis revealed the following:

Selection:

The proposed Integrated Use model was created by combining Lean (VSM, QFD) and VE (Job Plan) tactical level components, supporting **Finding 2**.

Order:

The authors proposed a model that features the addition of Lean components (VSM, QFD) to a sequenced and unaltered VE practice (VE Job Plan), supporting **Finding 11**.

Utilisation:

Odedairo & Bell (2010) did not specify the application areas for the proposed model. However, they recommended the model for application in Small to Medium Enterprises (SMEs) in developing countries. They asserted that the selected model components are simple, quick to learn and easy to understand and therefore suitable for SME utilisation.

Finding 20: Integrated Use model development can involve the utilisation of a sequential amalgamation of Lean and VE components based on their suitability to organisational size.

Purpose:

Odedairo & Bell (2010) added VSM and TQM (QFD) to the VE Job Plan to ensure that customer requirements and non-value adding activities are identified at the beginning of the value study. They asserted that this addition leads to an increase in the scope of VE, supporting **Finding 13**.

Table 19: Odedairo & Bell (2010) hybrid models and principles

Strength and Weakness Items	**Models**
Comparison Factor: 1. Key Success Factor **Weakness:** 1.1. VE Weakness: Success is highly dependent on the accuracy and integrity of information. **Comparison Factor:** 2. Approach **Strength:** 2.1. VE Strength: Foundation is the VE Job plan. Job Plan is easy to implement. VE is creative and function orientated	**Integrated Use Model:** The VE Job Plan model: **Step 1:** Information Gathering Phase: Pareto/ TQM: QFD/ Cost & Data Modelling/ VSM **Step 2:** Analyse Phase: Function Analysis/Target Costing/FAST Diagram **Step 3:** Creative Phase: Brainstorming/ Team Approach **Step 4:** Evaluation Phase: Return on Investment/ Pareto **Step 5:** Presentation/Implementation Phase: Training

Article 10: Kheradia (2011)

The tenth analysis was applied to the Kheradia (2001) study. Kheradia (2011) proposed the integration of Lean process flow analysis and VE process and product Function Analysis. He proposed an Integrated Use model based on the following questions:

- What is the initial state?
- How Lean is the system?
- What value does the system offer to customers?
- What Six Sigma level is the system operating at?
- What is the state of the new system after the change?

The proposed Integrated Use model involved the following steps:

- **Step 1**: Review: System Analysis
- **Step 2**: Observe: Process Analysis through Lean implementation
- **Step 3**: Probe: Process/Product Function/Cost Analysis through VE implementation
- **Step 4**: Sustain: Control of gains achieved in the first three steps (Six Sigma implementation)
- **Step 5**: Review: Iterative and Continuous Improvement until Quality Goals are reached

A SOUP analysis of the proposed model and its principles revealed the following:

Selection:

Kheradia (2011) developed an Integrated Use model suitable for tactical level quality management initiatives, supporting **Finding 2**.

Order:

The author did not provide sufficient information regarding the selected order; therefore, no interpretations were made.

Utilisation:

The author did not provide sufficient information regarding application areas; therefore, no interpretations were made.

Purpose:

The author did not provide sufficient information about the purpose of Lean and VE integration, therefore, no interpretations were made.

Article 11: Ogunbiyi et al. (2011)

The eleventh analysis was applied to the Ogunbiyi et al. (2011) study. They recommended the integration of Lean Construction and VE during the Project Briefing and Project Development stages to achieve value maximisation and to promote sustainability (Table 20). The authors conducted an analysis of Lean and VE similarities and differences to support this proposal. However, the authors did not propose a model that allows for SOUP analysis.

Article 12: De Hemmer (2012)

The twelfth was applied to the De Hemmer (2012) study. He proposed the integration of Lean Manufacturing and VE Product Design/Replacement to simultaneously achieve product and process optimisation (Table 21). The author completed a comparative analysis of Lean and VE to support this recommendation. However, the author did not propose a model that allows for SOUP analysis.

Table 20: Ogunbiyi et al. (2011) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Goal **Macro Similarities:** 1.1. Improve Value Delivery **Micro Difference:** 1.2 Lean value delivery from the Waste perspective & VE value delivery from the function perspective **Comparison Factor:** 2. Application Area **Macro Similarities:** 2.1. Sustainable Construction Projects **Micro Difference:** 2.2. Lean and VE are applied at different stages of the Project Life cycle	**Comparison Factor:** 1. Goal **Difference:** 1.1. Lean: Maximise value and minimise waste 1.2. VE: Maximise value within cost/quality/time requirements **Comparison Factor:** 2. Approach **Difference:** 2.1. Lean: Elimination of Non-Value add activities/ Improve the efficiency of resource conversion 2.2. VE: Satisfaction of basic function at best value **Comparison Factor:** 3. Focus **Difference:** 3.1. Lean: Improvement of workflow 3.2. VE: optimisation of whole life cycle cost **Comparison Factor:** 4. Application Area **Difference:** 4.1. Lean: Production 4.2. VE: Project Development	The authors did not provide a specific model. They recommended the integration of Lean Construction and VE during the Project Briefing and Project Development Stages to achieve value maximisation and to promote sustainability.

Table 21: De Hemmer (2012) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Approach **Macro Similarities:** 1.1. Value-based and Systematic **Micro Difference:** 1.2 Lean and VE have different Value definition and improve value from different perspectives. The Lean systematic approach is based on the 5 Lean principles; the VE systematic is based on the VE Job Plan. **Comparison Factor:** 2. Approach **Macro Similarities:** 2.1. People Involvement **Micro Difference:** 2.2. Lean aims to empower all people and create a Lean culture using an operating philosophy. VE involves a selected amount of people in a VE project.	**Comparison Factor:** 1. Application Area **Difference:** 1.1. Lean: Manufacturing/Production 1.2. VE: Projects, Research and Development and Innovation **Comparison Factor:** 2. Results **Difference:** 2.1. Lean: Optimal Process Design 2.2. VE: Transformation of products and process design	The author did not provide a specific model. They recommended the integration of Lean Manufacturing and VE Product Design/Replacement to simultaneously achieve product and process optimisation.

Article 13: Parker (2015)

The thirteenth analysis was applied to the Parker (2015) study. The author proposed the integration of Lean and VE. He asserted that Lean and VE similarities make the two methods complementary. Parker proposed one Integrated Use model (Table 22). The SOUP analysis revealed the following:

Selection:

The author developed an Integrated Use model that combines strategic level (5 Lean principles) and tactical level (VE practices and Lean tools and techniques) components, supporting **Finding 15**.

Order:

Parker (2015) proposed a model that features the addition of VE components (Function Analysis, FAST Diagram and the VE Job Plan) to a sequenced and unaltered Lean practice (The 5 Lean Principles), supporting **Finding 11.**

Utilisation:

The author did not provide sufficient information regarding application areas; therefore, no interpretations were made.

Purpose:

Parker (2015) asserted that Lean and VE are complementary and therefore proposed an Integrated Use model to be applied to achieve effective results, supporting **Finding 7**.

Table 22: Parker (2015) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Tools and Techniques **Macro Similarities:** 1.1. Value Stream Identification tools **Micro Difference:** 1.2 Lean: VSM and VE FAST diagram **Comparison Factor:** 2. Goal **Macro Similarities:** 2.1. Customer Value Creation **Micro Difference:** 2.2. Lean creates value through waste elimination and VE create value through function provision at the lowest cost. **Comparison Factor:** 3. Key Success Factors **Macro Similarities:** 3.1. Training, Executive Involvement, Investment and Systematic Effort **Micro Difference:** 3.2. Lean trains the entire organisation/VE trains Value team. Lean and VE have different executive involvement and investment requirements levels. Lean systematic effort: 5 Lean principles and VE is the VE Job Plan. **Comparison Factor:** 4. Implementation Requirement **Macro Similarities:** 4.1. Innovation conducive environment/culture **Micro Difference:**	**Comparison Factor:** 1. Focus **Difference:** 1.1. Lean: Operational Efficiency 1.2. VE: Whole Product (Function Perspective **Comparison Factor:** 2. Approach **Difference:** 2.1. Lean: Visual Control and Waste Elimination 2.2. VE: Function Analysis	**Integrated Use Model:** <u>Five Lean Principles Models:</u> **Step 1:** Specify Value: Function Analysis **Step 2:** Identify Value Stream: Lean VSM (waste perspective) and VE FAST (function perspective) **Step 3:** Flow: Lean Visual Control/7 waste types; VE Function Analysis **Step 4:** Pull: JIT, SMED, Single piece flow, Takt time, Cell Manufacturing **Step 5:** Pursue Perfection: Continuous Improvement/The VE Job Plan

4.2. Lean can create such a culture. VE does not influence culture.		

Article 14: Musa et al. (2016)

The fourteenth analysis was applied to the Musa et al. (2016) study. The authors did not provide a specific model. However, they recommended the integration of Lean Construction and VE from the *value perspective* to achieve synergy in *value understanding* and *value delivery*. The authors conducted a comparative analysis of Lean and VE and determined similarities, differences, strengths and weaknesses to support this proposal (Table 23). However, the authors did not propose a model that allows for a comprehensive SOUP analysis. Nevertheless, Musa et al. (2016) proposed the integration of Lean Construction and VE to achieve synergy in value understanding/delivery, supporting **Finding 14**.

Table 23: Musa et al. (2016) hybrid models and principles

Similarity Items	Difference Items	Strength & Weakness Items	Models
Comparison Factor: 1. Objective **Macro Similarity:** 1.1. Creating Value **Micro Difference:** 1.2. Lean waste perspective and VE function perspective value creation. **Comparison Factor:** 2. Origin **Macro Similarity:** 2.1. Manufacturing industry motivate by WWII **Micro Difference:** 2.2. Lean: Toyota to achieve product variety and VE: General Electric for procurement purposes **Comparison Factor:** 3. Tools and techniques **Macro Similarity:** 3.1. Recognised and Distinguishable tools **Micro Difference** 3.2. Lean Thinking: 5 Lean principles and tools and techniques. VE: The VE Job plan and its tools and techniques.	**Comparison Factor:** 1. Focus **Difference:** 1.1. Lean: Pull system, philosophy perspective 1.2. VE: Push system, service perspective **Comparison Factor:** 2. Approach **Difference:** 2.1. Lean: No formal implementation standard, context-based, ongoing operational strategy, flow focus & constant learning 2.2. VE: Only applied when opportunities are identified, ad hoc, problem analysis **Comparison Factor:** 3. Application Time/Area **Difference:** 3.1. Lean: Design & Construction/ Processes 3.2. VE: Design & Feasibility/ Products **Comparison Factor:** 4. Value Approach **Difference:** 4.1. Lean: Waste Elimination maintaining time/quality/cost 4.2. VE: Balance time/quality/cost **Comparison Factor:** 5. Customer Concept	**Comparison Factor:** 1. Value Concept **Strength/Weakness:** 1.1. Lean Weakness: No constant/universally understood value definition 1.2. VE Strength: Significant consensus on value definition **Comparison Factor:** 2. Approach **Weakness:** 2.1. VE Weakness: Susceptible to cost-cutting misinterpretation and once of implementation	**Integrated Use Model:** The authors did not provide a specific model. However, they recommended the integration of Lean Construction and VE from the *value perspective* to achieve synergy in *value understanding* and *value delivery*.

Comparison Factor: 4. Approach **Macro Similarity:** 4.1. Multidisciplinary, Team-based, Stakeholder involvement, Objective and Subjective value analysis **Micro Difference** 4.2. Lean: Multi-disciplinary from the enterprise perspective, once-off team formation, value is defined from the waste perspective. VE: Multidisciplinary from the VE study project perspective, the team formed on an ad hoc basis, value is defined from the function perspective. **Comparison Factor:** 5. Application **Macro Similarity:** 5.1. Applied in various sectors and misunderstood as cost-cutting exercise **Micro Difference** 5.2. Lean: applied to processes and production stages. VE applied to products/processes and design/conceptual stages.	**Difference:** 5.1. Lean: Internal/External/Next Customer 5.2. VE: Customer associated with the value system **Comparison Factor:** 6. Research & Development **Difference:** 6.1. Lean: High Research output: improve value understanding 6.2. VE: Low Research output: constant value concept **Comparison Factor:** 7. Academic Support **Difference:** 7.1. Lean: Theory development led by practitioners/academics 7.2. VE: Theory development mostly led by practitioners **Comparison Factor:** 8. Implementation Drivers **Difference:** 8.1. Lean: Waste elimination activities driven by people involved in the operation being studied 8.2. VE: VE activities are driven by people who are elected to be VE study participants		

Article 15: Ekanayake & Sandanayake (2017)

The fifteenth analysis was applied to the Ekanayake & Sandanayake et al. (2017) study. The authors proposed the complete integration of Lean Construction and VE. They identified opportunities for Lean and VE hybrid methodology formation using two approaches. Approach 1 involved the application of literature review techniques to determine Lean and VE similarities, differences and weaknesses. Approach 2 involved interviews with 6 industry experts. The authors combined these two approaches to rationalise the proposal of the LiVE Integrated Use model (Table 24). The SOUP analysis of this Integrated Use model revealed the following:

Selection:

Ekanayake & Sandanayake (2017) selected the 5 Lean Thinking principles (Strategic Level components), the VE Job plan (tactical level components) and Lean tools (tactical level components) to create an Integrated Use model which is a combination of strategic level and tactical level components, supporting **Finding 15**.

Order:

The authors combined the 5 Lean Principles with the VE Job plan to create the LiVE Integrated Use model. The model features combinations of Lean and VE components at every step.

Finding 21: Integrated Use model can comprise of an amalgamation Lean and VE components at every step in the sequence.

However, the authors' 7-phase model has the structure of the VE Job Plan. The recommended LiVE approach involves the addition of Lean principles to a sequenced and unaltered VE structure, supporting **Finding 11**.

Utilisation:

The author did not provide sufficient information regarding application areas; therefore, no interpretations were made.

Purpose:

Ekanayake & Sandanayake (2017) suggested an Integrated Use model where Lean principles and the VE Job plan are interdependent, connected and interact. They proposed this model for the purpose of achieving Lean and VE synergy, supporting **Finding 14**.

Table 24: Ekanayake & Sandanayake (2017) hybrid models and principles

Similarity Items	Difference Items	Strength & Weakness Items	Models
Comparison Factor: 1. Focus **Macro Similarity:** 1.1. Customer Value **Micro Difference:** 1.2. Lean waste perspective and VE function perspective customer value definition. **Comparison Factor:** 2. Approach **Macro Similarity:** 2.1. Systematic and Reduces Costs **Micro Difference:** 2.2. Lean Thinking: 5 Lean Principles. VE: VE Job Plan. **Comparison Factor:** 3. Aim **Macro Similarity:** 3.1. Reduce Costs/Minimise Waste/Optimise Quality/ Deliver Value **Micro Difference** 3.2. Lean achieves aim from waste elimination perspective and VE achieves aim from function provision perspective.	**Comparison Factor:** 1. Aim **Difference:** 1.1. Lean: Elimination of Non-Value add-in processes 1.2. VE: Improve functionality as lowest cost in projects **Comparison Factor:** 2. Origin **Difference:** 2.1. Lean: Toyota 2.2. VE: General Electric **Comparison Factor:** 3. Approach **Difference:** 3.1. Lean: Organisational Strategy and Philosophy 3.2. VE: Analytical tool **Comparison Factor:** 4. Goal **Difference:** 4.1. Lean: Improve organisational performance 4.2. VE: Achieve necessary function **Comparison Factor:** 5. Key Success Factors **Difference:**	**Comparison Factor:** 1. Scope **Weakness:** 1.1. Lean Weakness: Does not address material cost/price, does not address project functionality 1.2. VE Weakness: implementation is costly and time-consuming	**Integrated Use Model:** <u>The LiVE model</u> **Step 1:** Value Establishment Phase: Lean Value Definition integrated into Pre-Study Phase. Specify scope and client requirements to achieve the client's value and perfection. **Step 2:** Value Analysis and Functional Requirements Phase: Function Analysis, Pull System and VSM **Step 3:** Value Creativity Phase: Propose creative ideas to improve Flow and eliminate non-value add activities **Step 4:** Value Evaluation Phase: Evaluate selected creative ideas for flow enhancements and select effective ideas **Step 5:** Value Development Phase: Create value flow development proposals and implementation plans **Step 6:** Value Verification Phase: Presentation to the client: VSM, creative ideas to enhance value

	5.1. Lean: Management Commitment, Planning, Team approach, Enterprise Training 5.2. VE: Management support, Planning, Communication, Experienced multi-disciplinary team, team training **Comparison Factor:** 6. Results **Difference:** 6.1. Lean: Cost reduction by waste elimination, quality improvement by pursuing perfection, time reduction by flow analysis 6.2. VE: Optimal cost for required function, optimal function-based quality, time reduction through creating new alternatives **Comparison Factor:** 7. Customer Value Approach **Difference:** 7.1. Lean: Value identified and addressed in Value Phase 7.2. VE: Customer needs are identified in the pre-study, customer value is addressed in Job Plan implementation **Comparison Factor:** 8. Approach **Difference:** 8.1. Lean: 5 Lean principles 8.2. VE: VE Job Plan		flow, clients pulled functional requirements and required perfection to be verified by the client. **Step 7:** Value Achievement Phase: New Functional requirements are Pulled while pursuing perfection and achieving Continuous Improvement.

5.2.2 Application Research Articles: Hybrid Models and Principles

Article 16: Chakravartty (1991)

The sixteenth analysis was applied to the Chakravartty (1991) study. The author proposed a Lean Manufacturing and VE hybrid. Chakravartty (1991) briefly discussed the similarities and differences between Lean and VE and used these to rationalise the proposal of an Interchangeable Use model. The author proposed and applied the model empirically. However, the author only applied the VE components of the model. The SOUP analysis of this Interchangeable Use model revealed the following:

Selection:

Chakravartty (1991) selected JIT Manufacturing (strategic level), the VE Job plan (tactical level), FAST Diagram (tactical level) and Function Analysis (tactical level) to create an Interchangeable Use model which is suitable for a combination of strategic level and tactical level initiatives.

Finding 22: Interchangeable Use models can be selected for a combination of strategic and tactical level initiatives.

Order:

This model involves the implementation of VE during the design stage followed by the implementation of Lean during the production stage. Lean and VE are utilised interchangeably at different product/process life cycle stages to achieve the same macro objective (cost reduction).

Finding 23: Interchangeable Use model implementation: Lean and VE can be applied in a substitutional manner at different product/process life cycle stages.

Chakravartty (1991) proposed the utilisation of VE and Lean in a substitutional manner to achieve the same macro-level objective (cost reduction), this model involves substitutional use based on a macro level similarity. Additionally, the recommended Interchangeable Use model involves the implementation of Lean and VE at different life cycle stages because of their micro-level differences.

Finding 24: Interchangeable Use models involve the substitutional use of Lean and VE based on macro-level similarities and micro-level differences.

The author proposed a model where VE is applied prior to Lean because VE is most suitable to early life cycle stage design activities.

Finding 25: Interchangeable Use model implementation: VE can be applied prior to Lean because of its suitability to product/process design activities

Utilisation:

The suggested Interchangeable Use model features the implementation of VE in one application area (product/process design) and the implementation of Lean in another (production processes).

Finding 26: Interchangeable Use models can involve the implementation of Lean and VE in dissimilar application areas

Purpose:

The author asserted that the proposed Lean and VE hybrid model is purposed to achieve synergy. However, Lean and VE are not interdependent, they do not interact and are not applied as a combination in this proposed model. Lean and VE are applied separately at different stages of the product/process life cycle. Therefore, limiting the ability to result in true synergy.

Table 25: Chakravartty (1991) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Motivation **Macro Similarities:** 1.1. Philosophy of excellence **Micro Difference:** 1.2. Lean: excellence is defined from the waste perspective. VE: excellence is defined from the function perspective.	**Comparison Factor:** 1. Application Area **Difference:** 1.1. Lean: Process 1.2. VE: Process and Products **Comparison Factor:** 2. Application Time (Product) **Difference:** 2.1. Lean: Product Maturity Stage 2.2. VE: Product Design and Growth Stages **Comparison Factor:** 3. Application Time (Process) **Difference:** 3.1. Lean: System Operation 3.2. VE: System Design/System Commissioning	**Interchangeable Use Model:** Design Stage: VE Job plan, Function Analysis, FAST Diagram applied in product design. (Reduce Cost/Improve Quality) Design Stage: VE Job Plan, Function Analysis, FAST Diagram applied in process design Production Stage: JIT Manufacturing application in operational processes.

Article 17: Lehman & Reiser (2004)

The seventeenth analysis was applied to the Lehman & Reiser (2014) study. The authors did not provide a specific model. However, they described how the Boldt Company applies an integrated Lean Construction and VE model. This model involves the integration of VE with the Lean Construction process to manage budgets, achieve cost reduction and increase value. The authors briefly highlighted Lean and VE similarities (Table 26). They asserted that these similarities make the two methods complementary. The authors did not propose a model that allows for a comprehensive SOUP analysis.

Table 26: Lehman & Reiser (2004) hybrid models and principles

Similarity Items	**Models**
Comparison Factor: 1. Measurable Results **Macro Similarities:** 1.1. Cost/Resources/Time Benefits **Micro Difference:** 1.2. Lean and VE utilise different approaches to achieve the outlined benefits.	The authors did not provide a specific model. However, they described how the Boldt Company applies a Lean Construction and VE integrated model. This model involves the integration of VE into the Lean Construction process to manage budgets, achieve cost reduction and increase value.

Article 18: Nassey (2004)

The eighteenth analysis was applied to the Nassey (2004) study. The author applied a Lean Layout and VE Process Analysis hybrid. Nassey (2004) briefly discussed the similarities and differences between Lean and VE and used these to generate an Interchangeable Use model (Table 27). The SOUP analysis of this Interchangeable Use model revealed the following:

Selection:

Nassey (2004) selected Lean Layout (tactical level), the VE Job plan (tactical level), FAST Diagram (tactical level) and Function Analysis (tactical level) to create an Interchangeable Use model suitable for tactical level initiatives.

Finding 27: Interchangeable Use models can be selected for tactical level initiatives.

Order:

Nassey (2004) applied VE and Lean in a substitutional manner to achieve the same macro-level objectives (elimination of non-value adding activities, cost minimisation and operation evaluation), this model involves substitutional use based on a macro level similarity. Additionally, the recommended Interchangeable Use model involves the implementation of Lean and VE in different application areas based on their micro-level differences. Nassey's (2004) use of Lean and VE in a substitutional manner based on macro similarities and micro differences supports **Finding 24**.

The applied model involves the application of Lean prior to the application of VE. The author justified this decision using the differences in application areas. Nassey (2004) explained that Lean was applied first because all improvement activities must begin at the shop floor where all activities occur.

Finding 28: Interchangeable Use model implementation: Lean can be implemented before VE if the Lean initiative takes place on the shop floor (where all activities occur).

Utilisation:

This applied model involved the implementation of Lean on the shop floor (Layout) followed by the implementation of VE in production processes. Lean and VE are utilised interchangeably in different application areas to achieve the same macro objective (elimination of non-value adding activities, cost minimisation and operation evaluation). This substitutional utilisation of Lean and VE in dissimilar application areas supports **Finding 26**.

Purpose:

The author utilised Lean and VE in a substitutional manner to achieve the same macro objectives (elimination of non-value adding activities, cost minimisation and operation evaluation) in different application areas.

Finding 29: Interchangeable Use models can be implemented to achieve the same macro objectives (eliminate NVA, minimise cost, evaluate operation) in dissimilar application areas.

Table 27: Nassey (2004) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Result **Macro Similarities:** 1.1. Reduce Non-Value Add (NVA) activities/Increase Value **Micro Difference:** 1.2. Lean: NVA removed from waste perspective, VE: NVA removed from function perspective. **Comparison Factor:** 2. Misconception **Macro Similarities:** 2.1. Only applied in large companies **Comparison Factor:** 3. Goal **Macro Similarities:** 3.1. Reduce costs while maintaining quality **Micro Difference:** 3.2. Lean: waste perspective, VE: function perspective **Comparison Factor:** 4. Focus **Macro Similarities:** 4.1. Satisfaction of customer needs **Micro Difference:** 4.2. Lean: waste perspective, VE: function perspective **Comparison Factor:**	**Comparison Factor:** 1. Focus **Difference:** 1.1. Waste Elimination 1.2. Elimination of unnecessary functions **Comparison Factor:** 2. Application Time **Difference:** 2.1. Lean: Early as possible 2.2. VE: Design/Concept Stages	**Interchangeable Use Model:** <u>Lean Layout & VE Process Model</u> <u>Part 1: Lean Layout</u> **Step 1:** Data Gathering: Lean Flow Analysis/ Lean Layout Analysis/Activity Relationship Diagrams **Step 2:** Process Chart application (Time, Distance, Method associated with processes) **Step 3:** Relationship Diagram application (Outline Reasons and Restrictions) **Step 4:** Generate Layout Alternatives **Step 5:** Evaluation <u>Part 2: VE Process Analysis</u> **Step 1:** Information Gathering Phase **Step 2:** Function Analysis Phase (Function Definition/ Function Worth/ Function Process Analysis/ FAST Diagram) **Step 3:** Creativity (Generate Alternatives) **Step 4:** Evaluation **Step 5:** Implementation

5. Tools **Macro Similarities:** 5.1. Utilise Visual Tools **Micro Difference:** 5.2. Lean: VSM/Visual Control tools; VE: FAST Diagram. **Comparison Factor:** 6. Approach **Macro Similarities:** 6.1. Team-Based **Micro Difference:** 6.2. Lean: once-off team composition within functional areas, VE: ad hoc team composition for VE project		

Article 19: Prahladaraj (2004)

The nineteenth analysis was applied to the Prahladaraj (2004) study. The author applied a Lean and VE hybrid model to supply chain system processes. Prahladaraj (2004) proposed one difference between Lean and VE and applied an Integrated Use model (Table 28). The SOUP analysis of this Integrated Use model revealed the following:

Selection:

Prahladaraj (2004) selected Lean process flow analysis (tactical level), FAST Diagram (tactical level), Function Analysis (tactical level) and Lean 7 types of waste (tactical level) to create an Integrated Use model suitable for tactical level initiatives, supporting **Finding 2**.

Order:

The applied Integrated Use model features amalgamated Lean and VE components at every step, supporting **Finding 21**.

Utilisation:

The author implemented both Lean and VE in the same application areas (supply chain processes), supporting **Finding 5**.

Purpose:

The author did not provide sufficient information regarding the purpose of hybrid formation; therefore, no interpretations were made.

Table 28: Prahladaraj (2004) hybrid models and principles

Difference Items	**Models**
Comparison Factor: 1. Focus **Difference:** 1.1. Waste Identification 1.2. Capability Identification	**Integrated Use Model** Supply Chain System Model **Step 1:** Process Visualisation: Flow Chart and FAST Diagram **Step 2:** Process Analysis: FAST Diagram and Lean Process Analysis **Step 3:** Identification of NVA functions (VE); Identification of NVA (Lean- 7 types of waste)

Article 20: Wixson (2005)

The twentieth analysis was applied to the Wixson (2005) study. Wixson (2005) combined VE, FMEA (Failure Mode Effect Analysis) and RCA (Root Cause Analysis) to form a Lean and VE hybrid model. TQM is a management approach that is part of the Lean Lexicon (Lean Enterprise Institute, n.d.) and FMEA is one of the techniques utilised in TQM. Additionally, the Lean Lexicon includes two types of RCA techniques, namely 5 whys and fishbone diagram. The author examined the differences and similarities among VE, FMEA and RCA and utilised this analysis to generate an Integrated Use model (Table 29). The SOUP analysis revealed the following:

Selection:

Wixson (2005) selected FMEA (tactical level), RCA (tactical level) and the VE Job Plan (tactical level) to create an Integrated Use model suitable for tactical level initiatives, supporting **Finding 2.**

Order:

The applied Integrated Use model has the structure of the VE Job Plan. FMEA and RCA are added to this sequenced and unaltered the VE Job Plan, supporting **Finding 11**.

Utilisation:

The author implemented VE, FMEA and RCA in the same application area (Quality Management), supporting **Finding 5.**

Purpose:

The author did not provide sufficient information regarding the purpose of hybrid formation; therefore, no interpretations were made.

Table 29: Wixson (2005) hybrid models and principles

Similarity Items	Difference Items	Strength & Weakness Items	Models
Comparison Factor: 1. Tools and Techniques **Macro Similarity:** 1.1. FAST & FMEA facilitate clear problem definition **Micro Difference:** 1.2. FAST: Function perspective, FMEA: failure perspective **Comparison Factor:** 2. Application Time **Macro Similarity:** 2.1. FMEA & FAST can be applied at design and production stages **Comparison Factor:** 3. Application Area **Macro Similarity:** 3.1. FMEA & FAST can be applied to design and operational problem solving **Micro Difference** 3.2. Lean achieves aim from waste elimination perspective and VE achieves aim from function provision perspective.	**Comparison Factor:** 1. Approach **Difference:** 1.1. Lean: FMEA identifies failures/ RCA identifies the root cause 1.2. VE: FAST identifies functions and logical relationships of functions	**Comparison Factor:** 1. Approach **Strength:** 1.1. VE Strength: Structured VE Job Plan	**Integrated Use Model:** <u>Job Plan Model</u> **Step 1:** Information Gathering **Step 2:** Function Analysis: Function Identification and FAST Diagram development **Step 3:** FMEA: Isolate failed functions List function failure modes Determine failure effects Failure Ranking Determine priority failures **Step 4:** RCA: Determine root cause of priority failures Numerical Ranking Identify controls to prevent root causes Test effectiveness of controls **Step 5:** Creativity Phase: Design alternatives to prevent failures **Step 6:** Evaluation Phase **Step 7:** Development Phase **Step 8:** Presentation/Implementation Phase

Article 21: Borgianni et al. (2010)

The twenty-first analysis was applied to the Borgianni et al. (2010) study. Borgianni et al. (2010) combined Gemba, VE value equation, Lean methodology and VE methodology to form a Lean and VE hybrid model. The authors briefly highlighted the differences and similarities between Lean and VE and used them to generate a model that involves both Integrated Use and Interchangeable Use (Table 30). However, the analysis of combined hybrid models is beyond the scope of this study, therefore the applied model was analysed from the Interchangeable Use perspective (the 6th step of the model). The SOUP analysis revealed the following:

Selection:

The 6th step of the applied model involves the substitutional use of VE methodology and Lean Methodology. During this step, VE can be applied in low value/low benefit conditions or Lean can be applied in low value/high resource use conditions. The application of Lean/VE is proposed for specific micro-level events/conditions, therefore, this Interchangeable Use model was selected for tactical level initiatives, supporting **Finding 27**.

Order:

The 6th step of the Borgianni et al. (2010) involves the use of VE and Lean in a substitutional manner to achieve the same macro-level objective (value increase). The author highlighted that the macro similarity between these two methods is: they both aim to increase value. Additionally, the recommended Interchangeable Use model involves the implementation of Lean and VE in different conditions (Lean: high resource conditions and VE: low benefit conditions) because of their micro-level differences. Therefore, this model supports **Finding 24** because it features the use of Lean and VE in a substitutional manner based on both macro similarities and micro differences.

Utilisation:

The authors proposed this model for application within product and service systems, where Lean and VE are implemented in the same application area. However, the 6th step of the model involves the substitutional utilisation of Lean and VE in different conditions (Lean: High resource use and VE: low customer benefit) to achieve the same macro objective (value increase).

Finding 30: Interchangeable Use models can involve the substitutional utilisation of Lean and VE in the same application area but in dissimilar application conditions.

Purpose:

The author proposed the substitutional use of Lean and VE to achieve the same objective (value increase) in the same application area but under two different application conditions.

Finding 31: Interchangeable Use models can be implemented to achieve the same macro objective (increase value) in the same application area but under dissimilar application conditions.

Table 30: Borgianni et al. (2010) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Aim **Macro Similarity:** 1.1. Increase Value **Micro Difference:** 1.2. Lean increases value through improved resource efficiency. VE increases value through trimming unnecessary functions.	**Comparison Factor:** 1. Application Area **Difference:** 1.1. Lean: Low value; high resource problem 1.2. VE: Low value, low benefit problem	**Interchangeable Use Model:** Value Model **Step 1:** Information Gathering: Lean Gemba to obtain Tacit knowledge **Step 2:** Model Building **Step 3:** Benefit Identification **Step 4:** Customer Benefit and Company Resource Use Comparison: VE Function Analysis **Step 5:** Identify the direction for value improvement **Step 6:** Required Change Identification: Low value, low benefit problem: Apply VE **OR** **Step 6:** Required Change Identification: Low value, high resource problem: Apply Lean

Article 22: Sacadura & Tenera (2011)

The twenty-second analysis was applied to the Sacadura & Tenera (2011) study. Sacadura & Tenera (2011) combined Lean components (VSM, Muda Analysis) and a VE component (Function Analysis) to form a Lean and VE hybrid model. The authors briefly highlighted the weaknesses of Lean and used these to justify the development of an Integrated Use model (Table 31). The SOUP analysis revealed the following:

Selection:

Sacadura & Tenera (2011) selected VSM (tactical level), Muda analysis (tactical level) and Functional Analysis (tactical level) to create an Integrated Use model suitable for tactical level initiatives, supporting **Finding 2.**

Order:

The applied Integrated Use model features the use of Lean for waste analysis and the use of VE for value/Function Analysis. The authors presented a model where Lean waste analysis processes are implemented before the VE value/Function Analysis processes. Sacadura & Tenera explained that the model involved Lean implementation prior to VE implementation because process waste should be eliminated prior to analysing the customer value that is created by the processes. However, the authors did not provide support for this recommendation. Additionally, the first step in Lean Thinking is value definition (as per 5 Lean principles), where initial value definition/analysis facilitates the implementation of VSM.

Utilisation:

The authors recommended that the model be used in manufacturing processes where Lean and VE are sequentially applied in the same application area (processes), supporting **Finding 5**.

Purpose:

Sacadura & Tenera (2011) highlighted various Lean weaknesses and proposed the integration of Lean and VE to overcome these weaknesses, supporting **Finding 12**.

Table 31: Sacadura & Tenera (2011) hybrid models and principles

Strength and Weakness Items	**Models**
Comparison Factor: 1. Approach **Weakness:** Lean Weakness: • No ability to understand customer value	**Integrated Use Model** **Step 1:** Process Selection **Step 2:** Application of process VSM **Step 3:** Value stream sub-process selection

• No innovation capability • Cannot detect waste in small processes	**Step 4:** Function Analysis of all sub-processes **Step 5:** User related and external client function supply analysis **Step 6:** Muda II analysis of sub-processes **Step 7:** Muda I and Functional Muda Analysis of sub-processes **Step 8:** Function Analysis Evaluation **Step 9:** Improvement Plan Development **Step 10:** Plan Implementation

Article 23: Wohnhas (2014)

The twenty-third analysis was applied to the Wohnhas (2014) study. Wohnhas (2014) described how the Whirlpool Corporation applied Lean and VE hybrid models by combining Lean components (Lean knowledge/resource efficiency techniques, Lean Culture, Standardization and FMEA) and one VE component (Function Analysis) because of their similarities and differences (Table 32). The author described two methods which the company uses during Lean and VE hybrid methodology implementation. However, only one Integrated Use model was identified. The SOUP analysis revealed the following:

Selection:

Wohnhas (2014) selected FMEA (tactical level) and Functional Analysis (tactical level) to create an Integrated Use model suitable for tactical level initiatives, supporting **Finding 2.**

Order:

The author proposed the implementation of Functional Analysis prior to FMEA. He recommended this order because Functional Analysis is used to generate inputs for subsequent FMEA application. The subsequent FMEA processes are directed by customer function requirements, supporting **Finding 4**.

Utilisation:

The applied Integrated Use model involved the sequenced utilisation of Lean and VE in the same application area (product development), supporting **Finding 5**.

Purpose:

The author did not provide sufficient information regarding the purpose of hybrid formation; therefore, no interpretations were made.

Table 32: Wohnhas (2014) hybrid models and principles

Similarity Items	Difference Items	Models
Comparison Factor: 1. Application Area **Macro Similarity:** 1.1. Project Definition **Micro Difference:** 1.2. Lean product development: Lean applied to processes, culture, efficiency activities. VE applied to priority definition and resource/capital allocation	**Comparison Factor:** 1. Knowledge Management Approach **Difference:** 1.1. Lean: Standardization of knowledge management processes and knowledge flow efficiency 1.2. VE: Translation of technical language to common language through Function Analysis **Comparison Factor:** 2. Resource Management Focus **Difference:** 2.1. Lean: Resource Efficiency 2.2. VE: Resource Allocation **Comparison Factor:** 3. Product Development Focus **Difference:** 3.1. Lean: Process Efficiency 3.2. VE: Product Properties	Lean Product Development Items: **Item 1:** Lean: • Knowledge Management Efficiency • Resource Efficiency • Create innovative environment • Standardization **Item 2**: VE: • Function Analysis o Cost Data Benchmarking o Translation of customer requirements o Knowledge transfer o Product property definition **Integrated Use Model:** Design Verification Plan **Step 1:** Determine Functions: Function Analysis **Step 2:** FMEA Application: Functions are inputs of the FMEA process

Article 24: Lee et al. (2016)

The twenty-fourth analysis was applied to the Lee et al. (2016) study. Lee et al. (2016) combined Lean components (VSM, Process Analysis, FMEA), VE components (Function Analysis, VE Job Plan) and other methods to form a Lean and VE hybrid model. The authors briefly highlighted Lean and VE differences/VE strengths and used these to justify the development of an Integrated Use model (Table 33). The SOUP analysis revealed the following:

Selection:

Lee et al. (2016) selected FMEA (tactical level), VSM (tactical level), Lean process analysis (tactical level), Function Analysis (tactical level) and the VE Job Plan (tactical level) to create an Integrated Use model suitable for tactical level initiatives, supporting **Finding 2**.

Order:

The applied Integrated Use model has the structure of the VE Job Plan. FMEA, Lean process analysis and VSM were added to this sequenced and unaltered VE Job Plan, supporting **Finding 11**.

Utilisation:

The applied Integrated Use model involves the sequenced utilisation of Lean and VE in the same application area (product development), supporting **Finding 5**.

Purpose:

The author did not provide sufficient information regarding the purpose of hybrid formation; therefore, no interpretations were made.

Table 33: Lee et al. (2016) hybrid models and principles

Difference Items	**Strength & Weakness Items**	**Models**
Comparison Factor: 1. Result **Difference:** 1.1. Lean: Reduction in resource use/Increase in value 1.2. VE: Optimal product/service performance **Comparison Factor:** 2. Application Area **Difference:** 2.1. Lean: Processes and systems 2.2. VE: Products and services	**Comparison Factor:** 1. Approach **Strength:** 1.1. VE Strength: Systematic procedure: the VE Job plan 1.2. Lean Strength: Waste Eliminating VSM tools	**Integrated Use Model:** **Step 1:** FMEA Phase: Process Analysis **Step 2:** Function Analysis Phase: Analysis of Hardware/Software and people **Step 3:** Contradiction Analysis and Creative Phase: TRIZ Implementation **Step 4:** Lean Thinking Phase: VSM application/ Process Analysis **Step 5:** Quality Improvement Phase: Six Sigma application **Step 6:** Evaluation Phase: Prioritisation of ideas generated in preceding phases **Step 7:** Development Phase: selected ideas transformed into high-value alternatives **Step 8:** Presentation Phase: high-value alternatives presentation to stakeholders **Step 9:** Implementation Phase: implementation of accepted high-value alternatives

6 Discussion

6.1 Synthesis

Overall, a total of 15 Development Research articles were examined using the SOUP (Selection, Order, Utilisation and Purpose) analysis. These 15 articles included 16 Integrated Use models, 2 Concurrent Use models and 0 Interchangeable Use models. Additionally, a total of 9 Application Research articles were examined using the SOUP analysis. These 9 articles included 5 Integrated Use models, 3 Interchangeable Use models and 0 Concurrent Use models. Overall, a total of 26 Lean and VE hybrid methodology models were examined (Table 34).

Table 34: Number of analysed hybrid models

Description	**Development Research: Number of models**	**Application Research: Number of models**	**Total number of models**
Integrated Use models	16	5	21
Interchangeable Use models	0	3	3
Concurrent Use models	2	0	2
Total	**18**	**8**	**26**

The models listed in Table 34 have principles/characteristics that are related to the level of model *selection*, the manner in which the model is *ordered*, the applications in which the models are *utilised* and the *purpose* of the models. The analysis of these characteristics revealed 31 findings, the findings are summarised in Tables 35 to 38.

Table 35 shows that *Interchangeable Use* models can be selected for tactical initiatives and combined strategic/tactical initiatives. Additionally, *Integrated Use* models can be selected for tactical, strategic and combined strategic/tactical level initiatives. However, *Concurrent Use* models can only be selected for tactical level initiatives. The differences observed between *Integrated Use* models and the other two models can be attributed to the fact that a high number (21) of *Integrated Use* models were analysed therefore resulting in more comprehensive findings. On the other hand, Lean is regarded as an operational philosophy that can influence organisational strategy and VE is described as an analytical tool that is often used for tactical activities (Cell & Arratia, 2003; Musa et al., 2016; Nayak, 2006). VE may be described as an analytical tool but Value Methodology involves three types of techniques. Value Methodology is comprised of Value Management (suitable for strategic initiatives), Value Engineering (suitable for tactical initiatives) and Value Analysis (suitable for technical initiatives) (VM Services, 2017). Therefore, the scope of Value Methodology allows for the Interchangeable Use and Concurrent Use model implementation for strategic level initiatives.

Table 35: SOUP Analysis Findings: Selection

	Interchangeable Use Models		**Concurrent Use Models**		**Integrated Use Models**	
Model Characteristic	**Finding Number**	**Description**	**Finding Number**	**Description**	**Finding Number**	**Description**
Selection	**Finding 22** [Article 16]	Selected for a combination of Strategic and Tactical Level initiatives	**Finding 1** [Article 1]	Selected for Tactical Level initiatives	**Finding 2** [Article 1, 2, 4, 5, 8, 9, 10, 19, 20, 22, 23, 24]	Selected for Tactical Level initiatives
	Finding 27 [Article 18, 21]	Selected for Tactical Level initiatives			**Finding 9** [Article 2,4]	Selected for Strategic Level initiatives
					Finding 15 [Article 6, 13, 15]	Selected for a combination of Strategic and Tactical Level initiatives

The definitions of the three model types indicate that Lean and VE can be applied in the following arrangements: Substitutional Lean and VE implementation (Interchangeable Use models), Simultaneous Lean and VE implementation (Concurrent Use models) and Sequenced Lean and VE implementation (Integrated Use models). The findings contained in Table 36 reveal additional characteristics of Lean and VE hybrid model arrangement. Firstly, the findings show that the arrangement of hybrid models can be selected only when certain requirements are satisfied. For instance, substitutional use is applied when a combination of macro-level similarities and micro-level differences are identified, this is expected because Nayak (2006) and Musa et al. (2016) all proposed that substitutional use is only possible when similarities exist. Secondly, the findings show that the arrangement of hybrid models can be selected to satisfy certain requirements. For example, simultaneous use is recommended when Lean and VE output alignment is required. Thirdly, another important factor in the hybrid model arrangement is whether Lean is implemented before VE or vice versa. This factor is irrelevant for Concurrent Use models and it is most significant for Integrated Use models because these models rely on the interdependence of Lean and VE. The findings indicate that, in the application of Interchangeable Use models, either Lean or VE can be implemented first, the decision is influenced by the product/process life cycle stage and the area in which the initiative occurs. Additionally, the findings show that in Integrated Use application, the decision is influenced by the focus of the initiative, the existence of implementation opportunities and the organisational culture. Lastly, another factor that influences the order is the model structure. This factor is particularly significant for Integrated Use models because they involve an amalgamation of Lean and VE components. The findings show that Integrated Use models can involve the addition of Lean components to an unaltered VE structure (or vice versa), the addition of VE to an unaltered Lean Six Sigma structure, or the amalgamation of Lean and VE at every step in the sequence that results in a new structure.

Table 36: SOUP Analysis Findings: Order

	Interchangeable Use Models		Concurrent Use Models		Integrated Use Models	
Model Characteristic	**Finding Number**	**Description**	**Finding Number**	**Description**	**Finding Number**	**Description**
Order	**Finding 24** [Article 16, 18, 21]	Lean and VE applied in a substitutional manner based on macro-level similarities and micro-level differences	**Finding 3** [Article 1]	Simultaneous Lean and VE implementation when hybrid initiative requires agreement between Lean and VE output to avoid defect, rework and *waiting* waste.	**Finding 4** [Article 1, 23]	VE implementation before Lean implementation to ensure subsequent steps are directed by customer function requirements.

	Finding 25 [Article 16]	VE implementation before Lean because VE is more suitable to early-stage product/process design activities			**Finding 10** [Article 2,5]	Lean implementation before VE to create opportunities for subsequent VE implementation
	Finding 28 [Article 18]	Lean implementation before VE if the Lean initiative takes place on the shop floor (where all activities occur)			**Finding 11** [Article 2, 4, 5, 9, 13, 15, 20, 24]	The addition of VE components to a sequenced and unaltered Lean practice or vice versa
					Finding 16 [Article 6]	Lean implementation before VE to ensure that the first step involves value definition
					Finding 17 [Article 6]	Lean implementation before VE to create an environment/culture where VE can be applied easily/successfully
					Finding 19 [Article 8]	The addition of VE components to a sequenced and unaltered Lean Six Sigma practice
					Finding 21 [Article 15,19]	An amalgamation of Lean and VE at every step in the sequence

One of the most commonly discussed Lean and VE differences is related to where (area) and when (time/stage) the methodologies can be applied (Borgianni et al., 2010; Chakravartty, 1991; De Hemmer, 2012; Lee et al., 2016; Mandelbaum et al., 2010; Musa et al., 2016; Nayak, 2006; Ogunbiyi et al., 2011; Shekari & Fallahian, 2007; Thorsen, 2005). Lean is often deemed most suitable for process improvement during construction and production stages, and VE is often deemed most suitable for product/service/project improvement during design, feasibility and planning stages. Table 37 shows that Interchangeable Use models can involve the substitutional application of Lean and VE in dissimilar application areas, in the same application areas but dissimilar application conditions and

it can also involve the substitutional application of Lean and VE at different stages of a product/process life cycle. Similarly, the findings show that Integrated Use models can involve the sequential application of Lean and VE in the same application area, in dissimilar application areas and it can also be based on the size of the organisation. The findings indicate that Concurrent Use models involve the application of Lean and VE in similar application areas only. However, literature proposes that Concurrent Use models can also involve the application of Lean and VE in dissimilar application areas (Cell & Arratia, 2003; Nayak, 2006).

Table 37: SOUP Analysis Findings: Utilisation

	Interchangeable Use Models		Concurrent Use Models		Integrated Use Models	
Model Characteristic	**Finding Number**	**Description**	**Finding Number**	**Description**	**Finding Number**	**Description**
Utilisation	**Finding 23** [Article 16]	Lean and VE applied in a substitutional manner in dissimilar product/process life cycle stages (VE-Design/ Lean-Production)	**Finding 6** [Article 1]	Simultaneous Lean and VE implementation in the same application area	**Finding 5** [Article 1, 2, 19, 20, 22, 23, 24]	Sequential Lean and VE implementation in the same application area
	Finding 26 [Article 16, 18]	Substitutional implementation of Lean and VE in dissimilar application areas			**Finding 18** [Article 6]	Sequential Lean and VE implementation in dissimilar application areas
	Finding 30 [Article 21]	Substitutional implementation of Lean and VE in the same application area but in dissimilar application conditions			**Finding 20** [Article 9]	The utilisation of sequential amalgamation of Lean and VE components based on their suitability to organisational size

Hybrid methodologies are formed for a specific purpose. There are purposes that can be achieved through the implementation of any of the three hybrid model types: expanding scope, overcoming weaknesses, improving effectiveness, developing competitive advantage and achieving a waste/value balance (Borgianni et al., 2010; Kheradia, 2011; Nassey, 2004; Odedairo & Bell, 2010; Sacadura & Tenera, 2011; Shekari & Fallahian, 2007). However, there are purposes that are unique to a specific model type. For instance, synergistic benefits can only be achieved through the implementation of Integrated Use models (Table 38).

On the other hand, Findings 29 and 31 show that Interchangeable Use models are the only models that can be purposed to achieve the same Lean and VE macro objectives (NVA elimination, cost minimisation, operation evaluation and value increase) in dissimilar areas and conditions. However, the utilisation characteristics (Table 37) of the other two models indicated that they too can be purposed to achieve similar macro objectives in dissimilar application areas. The main difference lies in how the macro objectives are achieved, whether they are achieved through mutually exclusive substitutional Lean and VE implementation (Interchangeable Use), mutually inclusive Lean and VE implementation (Concurrent Use) or sequential Lean and VE implementation (Integrated Use). Additionally, the analysis revealed that Integrated Use models can involve simultaneous and substitutional use of Lean and VE components within a sequence.

Table 38: SOUP Analysis Findings: Purpose

	Interchangeable Use Models		Concurrent Use Models		Integrated Use Models	
Model Characteristic	**Finding Number**	**Description**	**Finding Number**	**Description**	**Finding Number**	**Description**
Purpose	**Finding 29** [Article 18]	Achieve the same Lean and VE objectives (eliminate NVA, minimise cost, evaluate operation) in dissimilar application areas	**Finding 8** [Article 1]	Improve the effectiveness of individual Lean and VE methodologies	**Finding 7** [Article 1, 13]	Improve the effectiveness of individual Lean and VE methodologies
	Finding 31 [Article 21]	Achieve the same Lean and VE objective (value increase) in the same application area but in different application conditions			**Finding 12** [Article 2, 22]	Overcome weakness of individual Lean and VE methodologies
					Finding 13 [Article 2, 4, 9]	Expand the scope of individual Lean and VE methodologies
					Finding 14 [Article 5, 6, 8, 14, 15]	Realise synergistic benefits

6.2 Hybrid Model Selection Framework

It is evident that the three model types share certain characteristics, however, there are traits that are unique to each model type. Practitioners often use methodology attributes and differences to support selection (Mandelbaum et al., 2010). A similar approach was applied in this study. The model characteristics that were discovered in the SOUP analysis were supplemented with literature and this combination was utilised to develop the proposed model selection framework (Figure 23 and Figure 24). A total of 31 *findings* were obtained through SOUP analysis; however, only 30 *findings* were included in the proposed model. Finding 20 (related to the utilisation of sequential Lean and VE combinations in specific organisational size) was found to be too wide-ranging to be included in the *utilisation* element of the proposed framework. This framework does not only guide decision-making but it also indicates the initiatives (tactical or strategic) that the models can be *selected* for, the *order* in which Lean and VE model components can be arranged, the areas and conditions in which the models can be *utilised* and the *purpose* that can be achieved through model application.

According to the definition outlined in section 1.6, the framework generated in this study should comply with the following criteria (Booth & Carroll, 2015; Chay et al., 2015; Verbrugge, 2016):

- It must be a structure that enables the realisation of a defined goal
- It must answer "how-to" questions
- It must represent theory
- It must comprise of one or more models
- It must guide implementation.

The established framework complies with the above criteria because:

- It enables model selection
- It includes criteria that detail when and how to apply each model type
- It denotes Lean and VE hybrid methodology model theory
- It is composed of Interchangeable, Concurrent and Integrated Use models
- It directs Lean and VE hybrid model implementation

Furthermore, as outlined in section 2.4.2, the aim of the study was to develop a framework that aligns with current operational research trends. These trends favour the use of Multi-Criteria Decision Methods (MCDM) because they allow for computational execution which aligns with 4IR, additionally, these trends favour fact-based methods (such as Choosing by Advantages) that rely on attributes. This is why the various Interchangeable Use, Concurrent Use and Integrated Use model attributes were coded and utilised to establish multiple criteria that guide selection. The framework structure facilitates the use of MCDM and CBA.

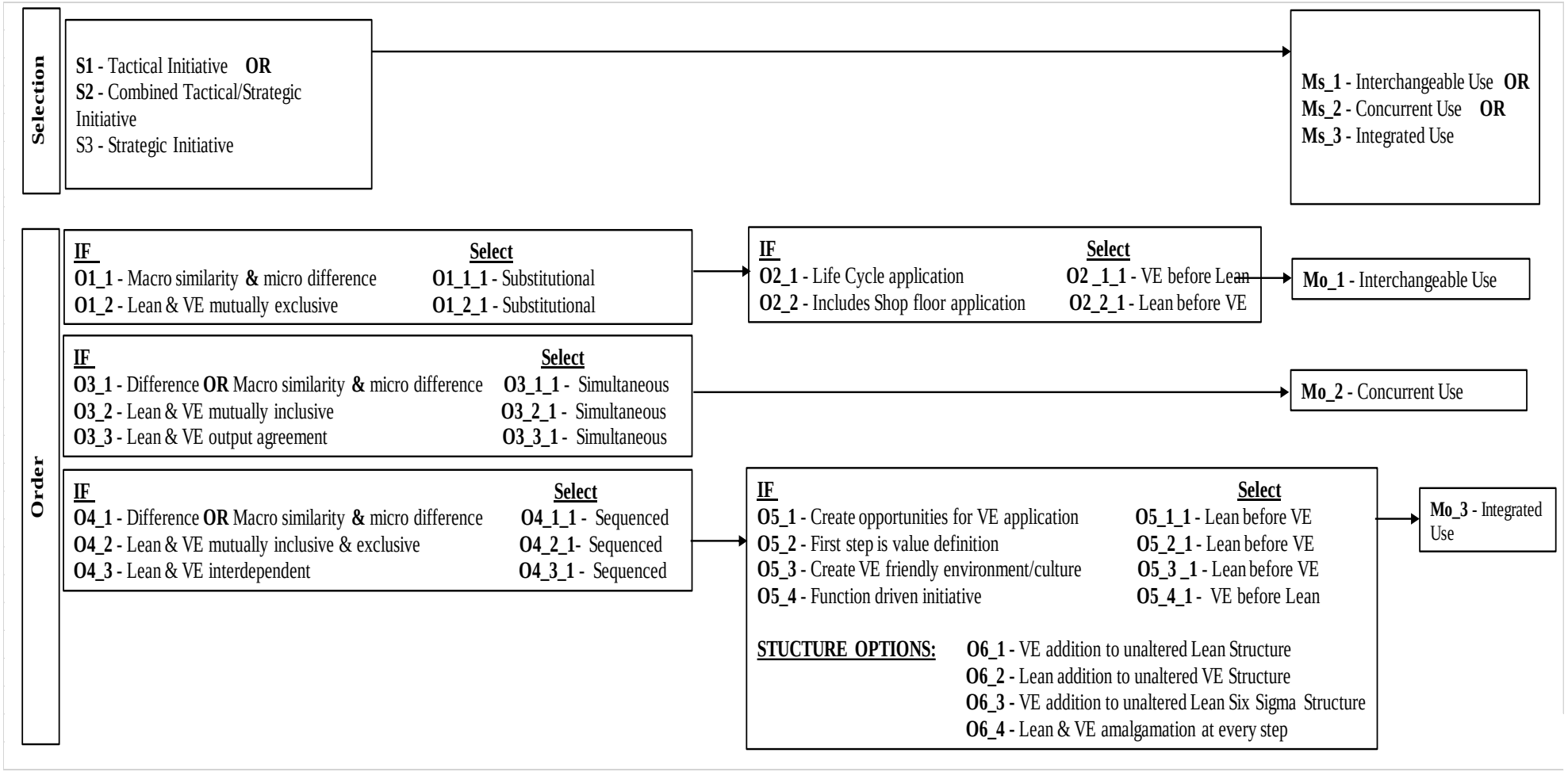


Figure 23: Lean and VE hybrid model Selection Framework (Part I)

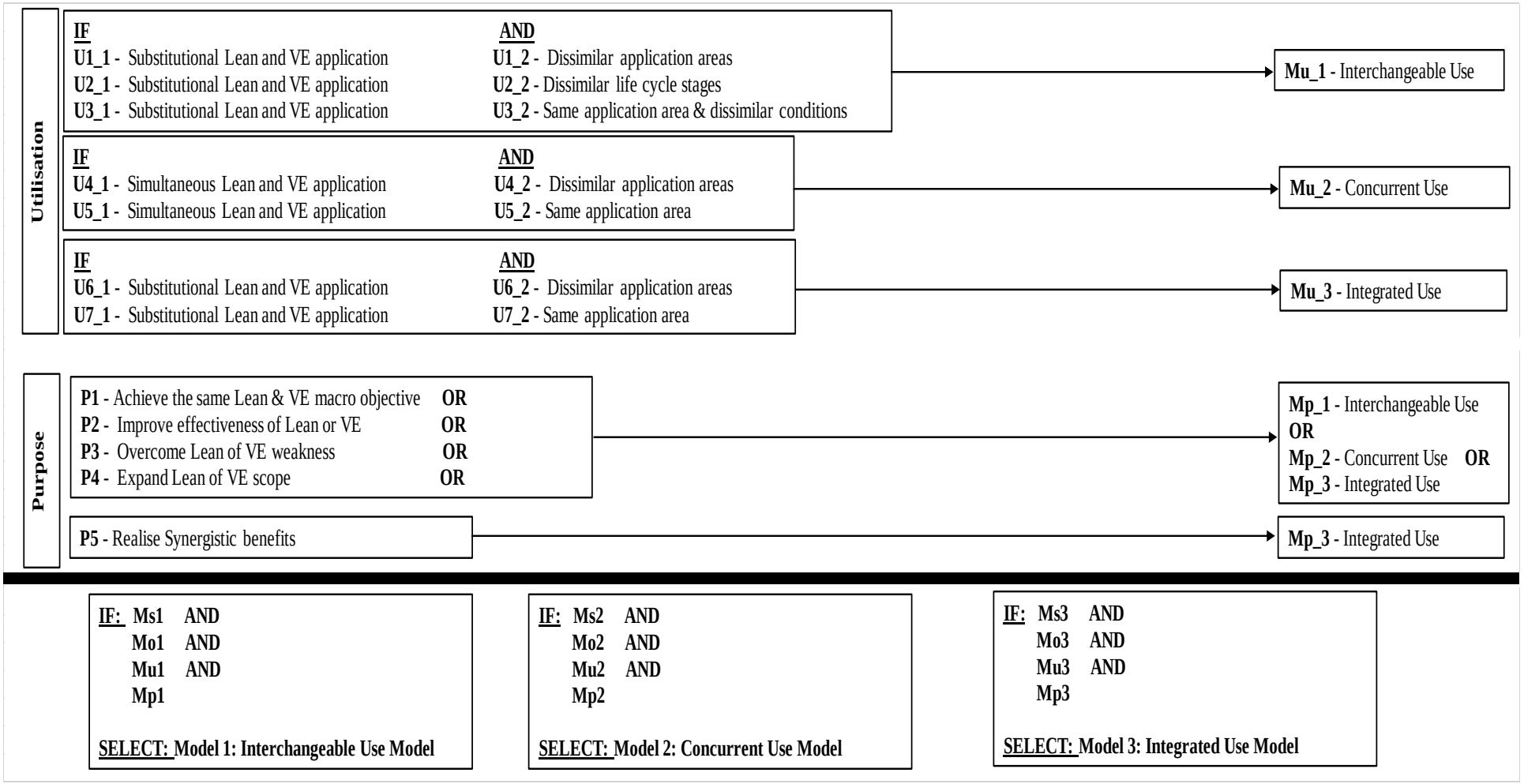


Figure 24: Lean and VE hybrid model Selection Framework (Part II)

6.3 Framework Limitations

The proposed framework is limited by the following factors:

- The proposed framework is based on 30 findings. The findings were discovered in the 24 research sample articles, the articles were selected based on the SLRM search strategy and the *inclusion/exclusion* criteria of this study. Therefore, the framework is limited by the number of findings, the search strategy and the *inclusion/exclusion* criteria.
- A total of 21 full-text articles were not obtained due to time and cost constraints. There may be additional model characteristics that are concealed in these sources and are therefore not represented in the framework.
- The findings were generated using proposed or applied Lean and VE activities, Mandelbaum et al. (2010) highlighted that theoretical activity-based analysis is limited by the differences between theory and practice.
- Framework development was based on an examination of general Lean and VE fundamentals. The *utilisation* element of the framework includes references to life cycle stages and shop floor activities however, the framework is intended for general multidisciplinary application and does not account for contextual differences.
- The majority of the findings were obtained from research that was conducted in the manufacturing industry.
- The majority of the articles utilised to develop this framework were classified as Development Research. These types of articles comprise of theoretical hybrid models that have not been tested empirically. Therefore, the framework is limited by a perspective that is largely theoretical.

6.4 Implications

The limitations of the framework present an opportunity for both industry and researchers to conduct both theoretical and empirical research to minimise the limitations. Despite the limitations, the findings of the research offer notable implications for the Lean and VE body of knowledge and for industry.

This research report adds to the Lean and VE body of knowledge by being a central access point for consolidated Lean and VE hybrid methodology data which includes an extensive list of Lean and VE weaknesses, strengths, similarities and differences; a list of 26 Lean and VE hybrid models and an extensive analysis of 4 Lean and VE hybrid model characteristics.

The reviewed literature did not provide distinct definitions for Lean and VE hybrid models. Additionally, some authors utilised *Integrated model* as a blanket term for all Lean and VE hybrid

models. This study adds to the Lean and VE body of knowledge by offering three model categories (Interchangeable Use, Integrated Use and Concurrent Use) that have distinct definitions. Moreover, Tables 11 to 33 contain practical examples of 2 Concurrent Use, 3 Interchangeable Use and 21 Integrated Use models that facilitate understanding of the definitions. Additionally, the 26 hybrid models can be utilised by industry, scholars and researchers for empirical testing and development.

The main output of this study is a Lean and VE hybrid model selection framework. The framework is based on four main model characteristics (selection, order, utilisation and purpose) and therefore offers a systematic decision-making approach that accounts for the type of initiative that is selected, the order of hybrid model components, the area in which the model components are utilised and the purpose of hybrid model implementation. It suggests a structured approach for the hybrid model building process.

7 Conclusions and Recommendations

7.1 Research Summary

This study sought to contribute to the evolution of CI methodologies. It was recognised that the advancement of CI methodologies manifests in several ways: formalisation, spread from manufacturing to other sectors and the formation of hybrid methodologies. The focus of this research was on hybrid methodologies, specifically Lean and VE hybrid methodology.

Literature indicated that the authors of Lean and VE hybrid methodology literature offer three main implementation models, namely Interchangeable Use, Concurrent Use and Integrated Use models. However, the literature did not include a model selection framework. Therefore, this study aimed to develop this framework by achieving the following objectives:

- Determine the variations of Interchangeable, Concurrent and Integrated Use models that are present in Lean and VE hybrid methodology literature
- Determine the principles that guide the proposal of Interchangeable, Concurrent and Integrated Use models
- Establish a model selection framework based on these principles

The literature review revealed that the authors of Lean and VE hybrid methodology literature use an assessment of Lean and VE similarities, differences, strengths and weaknesses to develop hybrid models. They employ multiple Comparative Analysis Factors (CAF) to compare Lean and VE theory (principles and concepts) and practices (activities, tools and techniques). The majority of these authors show alignment in their assessment of Lean and VE similarities and differences. However, there is variation in the assessment of Lean and VE strengths and weaknesses. These variations can be attributed to subjectivity and contextual factors. Furthermore, it was noted that Lean and VE were designed

separately without intending for them to be combined and this fact can either facilitate or impede the formation of hybrid methodology. Nevertheless, the authors agree that Lean and VE hybrid methodology has various potential benefits. Therefore, this study endeavoured to establish a framework to facilitate the implementation of this methodology. A framework that complies with established framework standards and aligns with operational research trends.

One of the most important characteristics of a framework is generalisability. Therefore, the Systematic Literature Review Methodology (SLRM) was selected because it facilitates the development of a generalisable framework. The SLRM search strategy involved the search for both grey and peer-reviewed literature using four search methods (free-text, manual, citation and bibliographic searching) to locate relevant papers from 17 multidisciplinary literature sources. 12 481 retrieved records were screened by title, 292 were screened by abstract and 82 papers were screened using full-text screening methods. The application of the outlined *inclusion/exclusion* criteria resulted in the selection of 24 relevant papers. These papers were analysed and classified by sector, author profession, publisher and document type. Furthermore, the papers were critically appraised based on applicability, validity and reproducibility factors. Finally, the relevant data were extracted and synthesized to develop a hybrid model selection framework.

The article overview revealed that the majority of the included research was conducted in the manufacturing industry, the majority of the papers were written from the academic perspective, were obtained from SAVE International and are conference papers. During the critical appraisal process, 2 articles were allocated a quality score that was less 50%; these papers are conference papers and the low score was due to lack of rigour. It was noted that practitioners do not have the same incentives that academics have when it comes to research and their approaches tend to favour relevance more than rigour. Once the context was established, the relevant data were extracted and synthesized to generate a framework. The articles were arranged by publication date and separated according to Development Research and Application research categories. 63% of the articles were classified as Development research, this means that the proposed models were theoretical and were not test empirically. 37% of the articles were classified as Application research, this means that the proposed models were tested empirically.

It was found that VSM, Waste Elimination, Function Analysis and the VE Job plan are the most commonly utilised Lean and VE techniques during hybrid model formation. Lean and VE similarities, differences, strengths, weaknesses and proposed hybrid models were extracted and analysed. A total of 26 (2 Concurrent Use, 3 Interchangeable Use, and 21 Integrated Use) hybrid models were obtained and analysed. The characteristics of these models were analysed based on *selection* (whether selected for tactical or strategic initiatives), *order* (the time and structure aspects of the model), *utilisation* (the area

or condition in which the models are applied) and *purpose* (the aim of hybrid model implementation). This SOUP analysis led to 31 findings. The findings were integrated and supplemented with literature to produce generalisable findings suitable for framework development.

The established framework does not only guide decision-making but it also indicates the initiatives that the models can be *selected* for, the *order* in which Lean and VE model components can be arranged, the areas and conditions in which the models can be *utilised* and the *purpose* that can be achieved through model application. The model structure is comprised of coded attributes and criteria that make it adaptable to Multi-Criteria Decision Methods and digitalisation. Most importantly, the framework is an answer to the following research question:
What framework can provide guidance for the selection of either Interchangeable, Concurrent or Integrated Use models in Lean and VE hybrid methodology

7.2 Conclusion

This research focused on Lean and VE hybrid methodology. It was recognised that this hybrid methodology can achieve results that are much greater than those achieved by individual Lean and VE initiatives. Lean and VE hybrid methodology has benefits. However, Lean and VE were not created with the intention to combine them and this fact can either facilitate or impede hybrid methodology implementation.

This study proposes that Lean and VE hybrid methodology can be applied using three types of models, namely Interchangeable Use, Concurrent Use and Integrated Use models. These models can be established by following a model development process. This process is comprised of the following steps:

- Examination of Lean and VE theory (concepts/principles) and practices (tools/techniques/activities)
- Completion of a Lean and VE comparative analysis using Comparative Analysis Factors. This step results in the determination of Lean and VE similarities and differences
- Completion of a Lean and VE comparative analysis using Comparative Analysis Factors while considering the organisational context. This step results in the determination of Lean and VE strengths and weaknesses or advantages and disadvantages within an organisational context.
- Integration of determined Lean and VE similarities, differences, strengths and weaknesses with the hybrid model selection framework to generate a Lean and VE hybrid methodology implementation plan

It was determined that hybrid models have characteristics that are related to *selection* (whether selected for tactical or strategic initiatives), *order* (the time and structure aspects of the model), *utilisation* (the area or condition in which the models are applied) and *purpose* (the aim of hybrid model implementation). These characteristics can be employed to guide hybrid methodology selection. Therefore, a model selection framework was established using these characteristics. The established framework does not only guide decision-making but is also indicates the initiatives that the models can be *selected* for, the *order* in which Lean and VE model components can be arranged, the areas and conditions in which the models can be *utilised* and the *purpose* that can be achieved through model application. However, the framework is subject to limitations.

This research is valuable to researchers, scholars and practitioners. It reports on the current state of the body of knowledge on Lean and VE hybrid methodology, it proposes a hybrid selection model that is intended to guide implementation and facilitate empirical research, and it adds structure to Lean and VE hybrid methodology implementation by proposing a systematic approach for hybrid model application.

7.3 Recommendations

The fact that Lean and VE were not designed to be combined makes Lean and VE hybrid methodology vulnerable to certain barriers. Therefore, the following future research is recommended to overcome this challenge:

- Investigate the key success factors for Lean and VE hybrid methodology implementation
- Explore how the differences in Lean and VE jargon, entry costs, resource utilisation, application strategy (VE: Adhoc and Lean: ongoing), training requirements (VE: training project team and Lean: training all employees) and team composition (VE: appointed project team and Lean: appointed Lean team/functional team) can be leveraged in a beneficial manner

This study was subject to financial and time constraints that limited its scope. Therefore, the following future research is recommended:

- Test and validate the proposed framework using empirical methods
- Repeat the systematic literature review using two or more reviewers

The majority of the findings that were utilised to develop the framework were obtained from a research perspective that was mostly theoretical and they were discovered in research that was mainly conducted in the manufacturing industry. Therefore, the following future research is recommended:

- Test the proposed framework by only analysing hybrid methodology models that have been examined empirically.

- Repeat this study using a literature sample from wide-ranging disciplines.

8 References

Ali, M. F., & Assaf, S. (2005). A Qualitative Comparison of Innovative Management Techniques in the Construction Industry. *45th Annual Conference of SAVE International*, 328–338.

Alukal, G., & Manos, A. (2006). *Lean Kaizen: A Simplified Approach to Process Improvements*. ASQ Quality Press.

Barker, R., & Naim, M. M. (2004). Housebuilding Supply Chains: Remove Waste – Improve Value. *The International Journal of Logistics Management*, *15*(2), 51–64. Scopus. https://doi.org/10.1108/09574090410700301

Bartunek, J. M., & Rynes, S. L. (2014). Academics and Practitioners Are Alike and Unlike: The Paradoxes of Academic–Practitioner Relationships. *Journal of Management*, *40*(5), 1181–1201. https://doi.org/10.1177/0149206314529160

Bearman, M., Smith, C. D., Carbone, A., Slade, S., Baik, C., Hughes-Warrington, M., & Neumann, D. L. (2012). Systematic review methodology in higher education. *Higher Education Research & Development*, *31*(5), 625–640. https://doi.org/10.1080/07294360.2012.702735

Bhuiyan, N., & Baghel, A. (2005). An overview of continuous improvement: from the past to the present. *Management Decision*, *43*(5), 761–771. https://doi.org/10.1108/00251740510597761

Boland, A., Cherry, M. G., & Dickson, R. (Eds.). (2017). *Doing a systematic review: a student's guide* (2nd edition). SAGE Publications.

Booth, A., & Carroll, C. (2015). Systematic searching for theory to inform systematic reviews: is it feasible? Is it desirable? *Health Information & Libraries Journal*, *32*(3), 220–235. https://doi.org/10.1111/hir.12108

Booth, A., Sutton, A., & Papaioannou, D. (2016). *Systematic approaches to a successful literature review* (Second edition). Sage.

Borgianni, Y., Cascini, G., & Rotini, F. (2010). Process value analysis for business process re-engineering. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *224*(2), 305–327. https://doi.org/10.1243/09544054JEM1460

Bozdogan, K. (2010). Evolution of the Lean Enterprise System. *Encyclopedia of Aerospace Engineering*. https://doi.org/10.1002/9780470686652.eae371

Cell, C. L., & Arratia, B. (2003). Creating Value With Lean Thinking and Value Engineering. *43rd SAVE International Annual Conference*, 12.

Chakravartty, U. (1991). *Value analysis and value engineering as a cost reduction tool and its relation with JIT manufacturing* [M.S., The University of Texas at El Paso]. http://0.search.proquest.com/docview/304005550/citation/28756CA5AA704FBCPQ/19

Chaurasia, B., Garg, D., & Agarwal, A. (2016). Framework to improve performance through implementing Lean Six Sigma strategies to oil exporting countries during recession or depression. *International Journal of Productivity and Performance Management*, *65*(3), 422–432. https://doi.org/10.1108/IJPPM-01-2015-0011

Chay, T., Xu, Y., Tiwari, A., & Chay, F. (2015). Towards lean transformation: the analysis of lean implementation frameworks. *Journal of Manufacturing Technology Management*, *26*(7), 1031–1052. https://doi.org/10.1108/JMTM-10-2013-0143

De Hemmer, O. (2012). Value(s) and management: There's value everywhere! *Innovation in the Value Methodology, ICVEM 2012*, 111–116. Scopus.

Dierickx, J. (2016). *Comparison of Lean Management in Japanese and Belgian Manufacturing SMEs* [M.Sc.]. GHENT UNIVERSITY.

Document Types in Grey Literature. (2004). Grey Net. http://www.greynet.org/greysourceindex/documenttypes.html

Dondofema, R. A., Matope, S., & Akdogan, G. (2017). LEAN APPLICATIONS: A SURVEY OF PUBLICATIONS WITH RESPECT TO SOUTH AFRICAN INDUSTRY. *South African Journal of Industrial Engineering*, *28*(1), 103–113. https://doi.org/10.7166/28-1-1660

Drucker, A. M., Fleming, P., & Chan, A.-W. (2016). Research Techniques Made Simple: Assessing Risk of Bias in Systematic Reviews. *Journal of Investigative Dermatology*, *136*(11), 109–114. https://doi.org/10.1016/j.jid.2016.08.021

Ekanayake, E. M. A. C., & Sandanayake, Y. G. (2017). LiVE approach: Lean integrated Value Engineering for construction industry. *Built Environment Project and Asset Management*, *7*(5), 518–533. https://doi.org/10.1108/BEPAM-11-2016-0071

El Khatib, Dr. M. M. (2015). Integrating Project Risk Management and Value Engineering in Tendering Processes. *International Journal of Engineering Research*, *4*(8), 442–445. https://doi.org/10.17950/ijer/v4s8/808

Fernandez-Solis, J., & Rybkowski, Z. (2012). A THEORY OF WASTE AND VALUE. *International Journal of Construction Project Management*, *4*, 1944–1436.

Finfgeld-Connett, D., & Johnson, E. D. (2013). Literature search strategies for conducting knowledge-building and theory-generating qualitative systematic reviews: *Literature search strategies*. *Journal of Advanced Nursing*, *69*(1), 194–204. https://doi.org/10.1111/j.1365-2648.2012.06037.x

Fink, A. (2005). *Conducting Research Literature Reviews: From the Internet to Paper*. SAGE.

Gonzalez Aleu, F., & Van Aken, E. M. (2016). Systematic literature review of critical success factors for continuous improvement projects. *International Journal of Lean Six Sigma*, *7*(3), 214–232. https://doi.org/10.1108/IJLSS-06-2015-0025

Gough, D. (2007). Weight of Evidence: a framework for the appraisal of the quality and relevance of evidence. *Research Papers in Education*, *22*(2), 213–228. https://doi.org/10.1080/02671520701296189

Haque, S., & Chaudhuri, S. R. (2015). Framework of Training for Lean Service. *Drishtikon: A Management Journal*, *7*(1). https://doi.org/10.21863/drishtikon/2015.7.1.011

Ho, D. C. K., Cheng, E. W. L., & Fong, P. S. W. (2000). Integration of value analysis and total quality management: The way ahead in the next millennium. *Total Quality Management and Business Excellence*, *11*(2), 179–186.

Kahraman, C. (2008). *Fuzzy Multi-Criteria Decision Making: Theory and Applications with Recent Developments*. Springer.

Kheradia, A. (2011). TALEVAS model: an integrated quality methodology. *The TQM Journal*, *23*(4), 403–422. https://doi.org/10.1108/17542731111139482

Kpamma, Z. E., Adjei-Kumi, T., Ayarkwa, J., & Adinyira, E. (2018). Choosing By Advantages incorporated framework for a user-involved design process. *Architectural Engineering and Design Management*, *14*(3), 194–217. https://doi.org/10.1080/17452007.2017.1341831

Kropsu-Vehkapera, H., & Isoherranen, V. (2018). Lean approach in knowledge work. *Journal of Industrial Engineering and Management*, *11*(3), 429–444. https://doi.org/10.3926/jiem.2595

Lane Davis, K. (2004). Finding Value in the Value Engineering Process. *Cost Engineering*, *46*(12), 24–27.

Lean Enterprise Institute. (n.d.). *Total Quality Management in the Lean Lexicon* ©. Retrieved August 28, 2019, from https://www.lean.org/lexicon/total-quality-management

Lean Enterprise Institute. (2000). *A Brief History of Lean*. https://www.lean.org/WhatsLean/History.cfm

Lean Manufacturing Tools. (n.d.). Top 50 Lean Tools | Comprehensive List for Lean Manufacturing and Service. Retrieved July 1, 2019, from http://leanmanufacturingtools.org/top-50-lean-tools-comprehensive-list-for-lean-manufacturing-and-service/

LeanKit. (2020, February 11). *Definition of Lean* [Text/html]. LeanKit. https://leankit.com/learn/lean/definition-of-lean/

Lee, L. J.-H., Leu, J.-D., & Huang, Y.-W. (2016). Using Ict to Improve Service Quality. *International Journal of Electronic Business Management; Hschinchu*, *14*, 53–61.

Lehman, T., & Reiser, P. (2004). Maximizing value & minimizing waste: Value engineering & lean construction. *SAVE International 44th Annual Conference Proceedings*. SAVE International Annual Conference.

Mahood, Q., Van Eerd, D., & Irvin, E. (2014). Searching for grey literature for systematic reviews: challenges and benefits. *Research Synthesis Methods*, *5*(3), 221–234. https://doi.org/10.1002/jrsm.1106

Mandelbaum, D. J., Williams, H., & Hermes, A. (2010). *Value Engineering Synergies with Lean Six Sigma* (IDA Paper P-4586; p. 118). Institute for Defense Analyses.

Manea, D. (2017). Value Analysis or Value Engineering- Establishing The Nomenclature And The Importance Level Of The Fubctions. *Review of General Management*, *26*(2), 97–104.

Mardani, A., Jusoh, A., MD Nor, K., Khalifah, Z., Zakwan, N., & Valipour, A. (2015). Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014. *Economic Research-Ekonomska Istraživanja*, *28*(1), 516–571. https://doi.org/10.1080/1331677X.2015.1075139

Musa, M. M., Pasquire, C., & Hurst, A. (2016). *Where Lean Construction and Value Management Meet*. 103–112.

Nassey, E. Zeth. (2004). Implementation of lean method and value analysis in the sandblasting production shop at Intersign Corporation. *University of Tennessee at Chattanooga*.

Nayak, D. B. (2006a). *LEAN MANUFACTURING and VALUE MANAGEMENT CONVERGENCE of DIVERGENT TOOLS*. https://www.academia.edu/9025230/LEAN_MANUFACTURING_and_VALUE_MANAGEMENT_CONVERGENCE_of_DIVERGENT_TOOLS

Nayak, D. B. (2006b). *LEAN MANUFACTURING and VALUE MANAGEMENT CONVERGENCE of DIVERGENT TOOLS*. https://www.academia.edu/9025230/LEAN_MANUFACTURING_and_VALUE_MANAGEMENT_CONVERGENCE_of_DIVERGENT_TOOLS

Odedairo, B. O., & Bell, D. (2010). Framework for introducing and implementing value methods: a novel toolkit for small and medium scale industries in developing nations. *International Journal of Basic & Applied Sciences IJBAS*, *9*(10), 130–146.

Ogunbiyi, O., Oladapo, A., & Goulding, J. (2011). Innovative Value Management: assessment of lean construction implementation. *COBRA 2011*, 696.

Okoli, C. (2015). *View From Giants' Shoulders: Developing Theory with Theory Mining Reviews*. Academia.edu. https://www.academia.edu/19557981/The_View_from_Giants_Shoulders_Developing_Theory_with_Theory-Mining_Systematic_Literature_Reviews

Ozkeser, B. (2018). *Lean Innovation Approach in Industry 5.0*. 8.

Parker, D. E. (2015). Lean as a value enhancing methodology. *SAVE Value Summit 2015*, 87–94. Scopus.

Pepper, M. P. J., & Spedding, T. A. (2010). The evolution of lean Six Sigma. *International Journal of Quality & Reliability Management*, *27*(2), 138–155. https://doi.org/10.1108/02656711011014276

Pieńkowski, M. (2014). Waste Measurement Techniques For Lean Companies. *International Journal of Lean Thinking*, *5*(1).

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., Britten, N., Roen, K., & Duffy, S. (2006). *Guidance on the conduct of narrative synthesis in systematic reviews: A product from the ESRC Methods Programme*. Lancaster University. https://doi.org/10.13140/2.1.1018.4643

Prahladaraj, Sripadharaj. (2004). Integration of lean manufacturing and value engineering techniques to improve the internal distribution system in a manufacturing company. *University of Tennessee at Chattanooga*.

Rader, T., Mann, M., Stansfield, C., Cooper, C., & Sampson, M. (2014). Methods for documenting systematic review searches: a discussion of common issues: DOCUMENTING SYSTEMATIC REVIEW SEARCHES. *Research Synthesis Methods*, *5*(2), 98–115. https://doi.org/10.1002/jrsm.1097

Ramesh, V., & Kodali, R. (2012). A decision framework for maximising lean manufacturing performance. *International Journal of Production Research*, *50*(8), 2234–2251. https://doi.org/10.1080/00207543.2011.564665

Sacadura, L. M. F. C., & Tenera, A. M. B. R. (2011). Integrating value and lean management in manufacturing processes. *2011 International Conference on Management and Service Science*, 1–5.

Salvatierra-Garrido, J., Pasquire, C., & Thorpe, A. (2008). Social housing in Chile: Opportunities to apply value concept in early stage of projects. *ARCOM 2008 - Proceedings of the 24th Annual Conference*, *1*, 371–380. Scopus.

Salvatierra-Garrido, Jose. (2011). Conceptualising value for construction: experience from social housing projects in Chile. *Loughborough University*. https://dspace.lboro.ac.uk/2134/9418

Sharma, L. K., Saxena, R. M., & Bajpai, L. (2014). An Explanatory Study of Lean Practices in Job Shop Production/ Special Job Production/ Discrete Production/ Batch Shop Production Industries. *Journal of Engineering Research and Application*, *4*(5), 94–101.

Shea, B. J., Hamel, C., Wells, G. A., Bouter, L. M., Kristjansson, E., Grimshaw, J., Henry, D. A., & Boers, M. (2009). AMSTAR is a reliable and valid measurement tool to assess the methodological quality of systematic reviews. *Journal of Clinical Epidemiology*, *62*(10), 1013–1020. https://doi.org/10.1016/j.jclinepi.2008.10.009

Shekari, A., & Fallahian, S. (2007a). A New Approach to Linking Value Engineering and Lean Methodology. *19th International Conference on Production Research*. International Conference on Production Research, Chile.

Shekari, A., & Fallahian, S. (2007b). A New Approach to Linking Value Engineering and Lean Methodology. *19th International Conference on Production Research*. International Conference on Production Research, Chile.

Singh, J., & Singh, H. (2015). Continuous improvement philosophy – literature review and directions. *Benchmarking: An International Journal*, *22*(1), 75–119. https://doi.org/10.1108/BIJ-06-2012-0038

Teeuwen, B. (2011). *Lean for the public sector the pursuit of perfection in government services*. CRC Press. http://www.netLibrary.com/urlapi.asp?action=summary&v=1&bookid=348074

Thorsen, W. C. (2005). Value Stream Mapping & VM. *45th Annual Conference of SAVE International*, 288–295.

Thürer, M., Tomašević, I., & Stevenson, M. (2017). On the meaning of 'Waste': review and definition. *Production Planning & Control*, *28*(3), 244–255. https://doi.org/10.1080/09537287.2016.1264640

Verbrugge, B. (2016, August 22). Best Practice, Model, Framework, Method, Guidance, Standard: towards a consistent use of terminology – revised. *Van Haren Publishing | BLOG*. https://www.vanharen.net/blog/general/best-practice-model-framework-method-guidance-standard-towards-consistent-use-terminology/

VM Services. (2017). *Value Engineering and Value Analysis Handbook*.

VM Services. (2019). *Application Examples*. VM Services Application Examples. https://www.vmservices.co.za/methodology-applied/application-examples

Wao, J. (2015). A Review of the Value Engineering Methodology: Limitations and Solutions for Sustainable Construction. *SAVE Value Summit 2015*, 1–7.

Watson, G. H. (2005). Putting value back into engineering. *ASQ World Conference on Quality and Improvement Proceedings*, *59*, 163.

Wixson, J. R. (2005). A Value Management Approach to Improving Quality Performance. *45th Annual Conference of SAVE International*, 129–146.

Wohnhas, S. (2014). Value management in lean product development. *SAVE Value Summit 2014*, 184–190. Scopus.

Womack, J. P., & Jones, D. T. (2003). *Lean thinking: banish waste and create wealth in your corporation* (Rev. and updated, 1. paperback ed). Simon & Schuster.

Appendix 1-A: Free-text and Manual Searching Results

Table 39: Scopus Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
1	03/06/2019	07:45	07:53	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Toyota Production System" AND "Value Methodology"	Searched all fields	3	2	1		
2	03/06/2019	07:57	08:06	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Toyota Production System" AND "Value Analysis"	Searched all fields	66	37	3		
3	03/06/2019	08:32	08:40	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Toyota Production System AND "Value Management"	Searched all fields	30	10	1		
4	03/06/2019	08:40	08:47	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Toyota Production System" AND "Value Engineering"	Searched all fields	72	14	2		
5	03/06/2019	08:52	08:56	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Lean" and "Value Methodology"	Searched all fields	44	29	14		
6	03/06/2019	08:59	09:05	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Lean" AND "Value Analysis"	Searched all fields	40	22	9		
7	03/06/2019	09:05	09:15	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Lean" AND "Value Management"	Searched all fields	44	23	14		
8	03/06/2019	09:15	09:30	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Lean" AND "Value Engineering"	Searched all fields	50	12	7	**65**	**43**
9	03/06/2019	09:38	09:44	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"CI" AND "Value Methodology"	Searched all fields	16	5	1		
10	03/06/2019	09:45	09:49	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"CI" AND "Value Management"	Searched all fields	11	6	3		
11	03/06/2019	10:36	10:56	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"CI" AND " Value Analysis"	Searched all fields	9	4	1		
12	03/06/2019	10:56	11:01	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"CI" AND "Value Engineering"	Searched all fields	82	26	2		
13	03/06/2019	11:05	11:16	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Kaizen" AND "Value Methodology"	Searched all fields	3	2	1		
14	03/06/2019	11:16	11:25	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Kaizen" AND "Value Management"	Searched all fields	32	7	2		
15	03/06/2019	11:25	11:28	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Kaizen" AND "Value Analysis"	Searched all fields	46	8	2		
16	03/06/2019	11:28	11:32	1960 - 03/06/2019	Free-text Searching	Scopus	1960 - 03/06/2019	"Kaizen" AND "Value Engineering"	Searched all fields	25	6	2		

Table 40: Emerald Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
17	04/06/2019	07:45	07:52	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Toyota Production System" AND "Value Methodology"	Advanced searched all fields; articles and chapters and case studies	1	1	1	**16**	**2**
18	04/06/2019	07:58	08:02	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Toyota Production System" AND "Value Analysis"	Advanced searched all fields; articles and chapters and case studies	28	13	1		
19	04/06/2019	07:52	07:56	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Toyota Production System AND "Value Management"	Advanced searched all fields; articles and chapters and case studies	14	3	0		
20	04/06/2019	08:05	08:10	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Toyota Production System" AND "Value Engineering"	Advanced searched all fields; articles and chapters and case studies	11	2	1		
21	04/06/2019	08:13	08:15	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Lean" and "Value Methodology"	Advanced searched all fields; articles and chapters and case studies	7	5	1		
22	04/06/2019	08:17	08:41	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Lean" AND "Value Analysis"	Advanced searched all fields; articles and chapters and case studies	207	41	2		
23	04/06/2019	08:45	09:38	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Lean" AND "Value Management"	Advanced searched all fields; articles and chapters and case studies	106	9	0		
24	04/06/2019	09:40	09:56	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Lean" AND "Value Engineering"	Advanced searched all fields; articles and chapters and case studies	122	5	2		
25	04/06/2019	10:00	10:04	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"CI" AND "Value Methodology"	Advanced searched all fields; articles and chapters and case studies	9	1	1		
26	04/06/2019	10:05	10:17	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"CI" AND "Value Management"	Advanced search all fields; articles and chapters and case studies	127	3	0		
27	04/06/2019	10:17	10:30	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"CI" AND " Value Analysis"	Advanced search all fields; articles and chapters and case studies	201	6	2		
28	04/06/2019	10:40	10:55	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"CI" AND "Value Engineering"	Advanced search all fields; articles and chapters and case studies	128	2	2		
29	04/06/2019	11:17	11:20	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Kaizen" AND "Value Methodology"	Advanced search all fields; articles and chapters and case studies	1	1	1		
30	04/06/2019	11:21	11:30	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Kaizen" AND "Value Management"	Advanced search all fields; articles and chapters and case studies	14	0	0		
31	04/06/2019	11:30	11:46	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Kaizen" AND "Value Analysis"	Advanced search all fields; articles and chapters and case studies	61	1	1		
32	04/06/2019	11:47	11:52	1994 - 04/06/2019	Free-text Searching	Emerald	1994 - 04/06/2019	"Kaizen" AND "Value Engineering"	Advanced search all fields; articles and chapters and case studies	50	1	1		

Table 41: Wiley Online Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
33	05/06/2019	10:37	10:38	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Toyota Production System" AND "Value Methodology"	Advanced searched all fields; journals only	0	0	0		
34	05/06/2019	10:38	10:43	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Toyota Production System" AND "Value Analysis"	Advanced searched all fields; journals only	9	2	1		
35	05/06/2019	10:43	10:53	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Toyota Production System AND "Value Management"	Advanced searched all fields; journals only	3	1	0		
36	05/06/2019	10:54	10:56	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Toyota Production System" AND "Value Engineering"	Advanced searched all fields; journals only	4	2	0		
37	05/06/2019	11:02	11:08	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Lean" and "Value Methodology"	Advanced searched all fields; journals only	1	0	0		
38	05/06/2019	11:10	11:28	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Lean" AND "Value Analysis"	Advanced searched all fields; journals only	151	1	0		
39	05/06/2019	11:28	11:35	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Lean" AND "Value Management"	Advanced searched all fields; journals only	53	0	0		
40	05/06/2019	11:55	12:15	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Lean" AND "Value Engineering"	Advanced searched all fields; journals only	58	3	0	**3**	**2**
41	05/06/2019	12:21	12:24	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"CI" AND "Value Methodology"	Advanced searched all fields; journals only	1	0	0		
42	05/06/2019	12:25	12:32	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"CI" AND "Value Management"	Advanced searched all fields; journals only	90	4	1		
43	05/06/2019	12:33	12:43	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"CI" AND " Value Analysis"	Advanced searched all fields; journals only	55	4	1		
44	05/06/2019	12:44	12:51	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"CI" AND "Value Engineering"	Advanced searched all fields; journals only	56	3	0		
45	05/06/2019	12:52	12:53	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Kaizen" AND "Value Methodology"	Advanced searched all fields; journals only	0	0	0		
46	05/06/2019	12:54	12:55	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Kaizen" AND "Value Management"	Advanced searched all fields; journals only	4	0	0		
47	05/06/2019	12:26	12:59	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Kaizen" AND "Value Analysis"	Advanced searched all fields; journals only	14	3	0		
48	05/06/2019	13:00	13:10	1997 - 05/06/2019	Free-text Searching	Wiley Online	1997 - 05/06/2019	"Kaizen" AND "Value Engineering"	Advanced searched all fields; journals only	11	1	0		

Table 42: Taylor and Francis Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
49	07/06/2019	08:36	08:37	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Toyota Production System" AND "Value Methodology"	Advanced searched all fields; articles only	0	0	0	**45**	**25**
50	07/06/2019	08:40	08:41	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Toyota Production System" AND "Value Analysis"	Advanced searched all fields; articles only	15	7	0		
51	07/06/2019	08:44	09:00	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Toyota Production System AND "Value Management"	Advanced searched all fields; articles only	8	3	0		
52	07/06/2019	09:09	09:10	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Toyota Production System" AND "Value Engineering"	Advanced searched all fields; articles only	11	2	0		
53	07/06/2019	09:13	09:14	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Lean" and "Value Methodology"	Advanced searched all fields; articles only	6	4	1		
54	07/06/2019	09:15	09:16	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Lean" AND "Value Analysis"	Advanced searched all fields; articles only	184	27	10		
55	07/06/2019	14:25	14:30	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Lean" AND "Value Management"	Advanced searched all fields; articles only	93	29	6		
56	07/06/2019	14:36	14:47	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Lean" AND "Value Engineering"	Advanced searched all fields; articles only	132	26	8		
57	07/06/2019	14:50	14:58	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"CI" AND "Value Methodology"	Advanced searched all fields; articles only	2	0	0		
58	07/06/2019	14:58	15:07	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"CI" AND "Value Management"	Advanced searched all fields; articles only	77	16	3		
59	07/06/2019	15:11	15:12	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"CI" AND " Value Analysis"	Advanced searched all fields; articles only	153	14	9		
60	07/06/2019	15:38	15:52	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"CI" AND "Value Engineering"	Advanced searched all fields; articles only	110	19	4		
61	07/06/2019	15:54	15:54	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Kaizen" AND "Value Methodology"	Advanced searched all fields; articles only	0	0	0		
62	07/06/2019	15:55	15:55	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Kaizen" AND "Value Management"	Advanced searched all fields; articles only	10	3	1		
63	07/06/2019	15:56	16:02	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Kaizen" AND "Value Analysis"	Advanced searched all fields; articles only	38	6	2		
64	07/06/2019	16:03	16:07	1997 - 07/06/2019	Free-text Searching	Taylor and Francis	1997 - 07/06/2019	"Kaizen" AND "Value Engineering"	Advanced searched all fields; articles only	39	1	1		

Table 43: ProQuest Central Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
65	12/06/2019	06:30	06:39	All Dates	Free-text Searching	Proquest Central	All Dates	"Toyota Production System" AND "Value Methodology"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	9	8	3	**45**	**17**
66	12/06/2019	06:41	06:43	All Dates	Free-text Searching	Proquest Central	All Dates	"Toyota Production System" AND "Value Analysis"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	286	22	5		
67	12/06/2019	07:44	07:57	All Dates	Free-text Searching	Proquest Central	All Dates	"Toyota Production System AND "Value Management"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	112	7	3		
68	12/06/2019	08:08	08:09	All Dates	Free-text Searching	Proquest Central	All Dates	"Toyota Production System" AND "Value Engineering"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	221	9	3		
69	12/06/2019	08:31	08:51	All Dates	Free-text Searching	Proquest Central	All Dates	"Lean" and "Value Methodology"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	213	14	2		
70	12/06/2019	08:52	08:56	All Dates	Free-text Searching	Proquest Central	All Dates	"Lean" AND "Value Analysis"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	3972	16	5		
71	12/06/2019	09:25	09:27	All Dates	Free-text Searching	Proquest Central	All Dates	"Lean" AND "Value Management"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	1265	4	1		
72	12/06/2019	09:49	10:07	All Dates	Free-text Searching	Proquest Central	All Dates	"Lean" AND "Value Engineering"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	2035	5	4		
73	12/06/2019	10:08	10:09	All Dates	Free-text Searching	Proquest Central	All Dates	"CI" AND "Value Methodology"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	73	2	1		
74	12/06/2019	10:20	10:22	All Dates	Free-text Searching	Proquest Central	All Dates	"CI" AND "Value Management"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	1137	6	1		
75	12/06/2019	10:40	10:41	All Dates	Free-text Searching	Proquest Central	All Dates	"CI" AND " Value Analysis"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	1927	18	8		
76	12/06/2019	11:03	11:05	All Dates	Free-text Searching	Proquest Central	All Dates	"CI" AND "Value Engineering"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	1955	7	5		
77	12/06/2019	11:28	11:29	All Dates	Free-text Searching	Proquest Central	All Dates	"Kaizen" AND "Value Methodology"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	30	1	1		
78	12/06/2019	11:37	11:38	All Dates	Free-text Searching	Proquest Central	All Dates	"Kaizen" AND "Value Management"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	161	2	1		
79	12/06/2019	11:55	11:56	All Dates	Free-text Searching	Proquest Central	All Dates	"Kaizen" AND "Value Analysis"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	402	4	2		
80	12/06/2019	12:16	12:18	All Dates	Free-text Searching	Proquest Central	All Dates	"Kaizen" AND "Value Engineering"	Advanced searched all fields, all sources (including grey lit) and all document types in English language	476	2	0		

Table 44: SAGE Journals Search Methods and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
81	14/06/2019	09:14	09:16	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Toyota Production System" AND "Value Methodology"	Advanced searched all fields	0	0	0	**1**	**1**
82	14/06/2019	09:16	09:17	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Toyota Production System" AND "Value Analysis"	Advanced searched all fields	6	2	0		
83	14/06/2019	09:22	09:23	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Toyota Production System AND "Value Management"	Advanced searched all fields	5	3	0		
84	14/06/2019	09:26	09:27	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Toyota Production System" AND "Value Engineering"	Advanced searched all fields	8	0	0		
85	14/06/2019	09:32	09:34	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Lean" and "Value Methodology"	Advanced searched all fields	2	0	0		
86	14/06/2019	09:35	09:36	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Lean" AND "Value Analysis"	Advanced searched all fields	84	5	0		
87	14/06/2019	09:57	09:58	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Lean" AND "Value Management"	Advanced searched all fields	37	0	0		
88	14/06/2019	10:03	10:07	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Lean" AND "Value Engineering"	Advanced searched all fields	50	4	1		
89	14/06/2019	11:30	11:34	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"CI" AND "Value Methodology"	Advanced searched all fields	3	0	0		
90	14/06/2019	11:35	11:37	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"CI" AND "Value Management"	Advanced searched all fields	43	0	0		
91	14/06/2019	11:42	11:43	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"CI" AND " Value Analysis"	Advanced searched all fields	58	0	0		
92	14/06/2019	11:53	11:53	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"CI" AND "Value Engineering"	Advanced searched all fields	41	0	0		
93	14/06/2019	12:01	12:02	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Kaizen" AND "Value Methodology"	Advanced searched all fields	0	0	0		
94	14/06/2019	12:03	12:04	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Kaizen" AND "Value Management"	Advanced searched all fields	4	0	0		
95	14/06/2019	12:05	12:06	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Kaizen" AND "Value Analysis"	Advanced searched all fields	12	0	0		
96	14/06/2019	12:08	12:09	1999 - 14/06/2019	Free-text Searching	SAGE Journals Online	1999 - 14/06/2019	"Kaizen" AND "Value Engineering"	Advanced searched all fields	13	0	0		

Table 45: Web of Science Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
97	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Toyota Production System" AND "Value Methodology"	Advanced searched all fields	0	0	0	**8**	**5**
98	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Toyota Production System" AND "Value Analysis"	Advanced searched all fields	0	0	0		
99	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Toyota Production System AND "Value Management"	Advanced searched all fields	0	0	0		
100	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Toyota Production System" AND "Value Engineering"	Advanced searched all fields	0	0	0		
101	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Lean" and "Value Methodology"	Advanced searched all fields	0	0	0		
102	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Lean" AND "Value Analysis"	Advanced searched all fields	12	9	1		
103	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Lean" AND "Value Management"	Advanced searched all fields	8	4	2		
104	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Lean" AND "Value Engineering"	Advanced searched all fields	4	4	3		
105	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"CI" AND "Value Methodology"	Advanced searched all fields	0	0	0		
106	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"CI" AND "Value Management"	Advanced searched all fields	2	1	0		
107	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"CI" AND " Value Analysis"	Advanced searched all fields	3	3	1		
108	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"CI" AND "Value Engineering"	Advanced searched all fields	1	0	0		
109	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Kaizen" AND "Value Methodology"	Advanced searched all fields	0	0	0		
110	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Kaizen" AND "Value Management"	Advanced searched all fields	0	0	0		
111	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Kaizen" AND "Value Analysis"	Advanced searched all fields	1	0	0		
112	17/06/2019	08:46	09:10	1945 - 17/06/2019	Free-text Searching	Web of Science	1945 - 17/06/2019	"Kaizen" AND "Value Engineering"	Advanced searched all fields	1	1	1		

Table 46: WorldCat Search Methods and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
113	18/06/2019	08:22	08:23	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Toyota Production System" AND "Value Methodology"	Searched all fields	6	1	0	7	5
114	18/06/2019	08:24	08:25	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Toyota Production System" AND "Value Analysis"	Searched all fields	13	1	0		
115	18/06/2019	08:32	08:33	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Toyota Production System AND "Value Management"	Searched all fields	24	2	0		
116	18/06/2019	08:36	08:36	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Toyota Production System" AND "Value Engineering"	Searched all fields	13	0	0		
117	18/06/2019	08:41	08:42	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Lean" and "Value Methodology"	Searched all fields	102	13	0		
118	18/06/2019	08:54	05:55	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Lean" AND "Value Analysis"	Searched all fields	311	22	2		
119	18/06/2019	09:20	09:20	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Lean" AND "Value Management"	Searched all fields	390	13	3		
120	18/06/2019	09:51	09:51	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Lean" AND "Value Engineering"	Searched all fields	285	4	2		
121	18/06/2019	10:08	10:09	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"CI" AND "Value Methodology"	Searched all fields	56	1	0		
122	18/06/2019	10:15	10:15	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"CI" AND "Value Management"	Searched all fields	186	4	0		
123	18/06/2019	10:29	10:30	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"CI" AND " Value Analysis"	Searched all fields	187	0	0		
124	18/06/2019	10:40	10:40	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"CI" AND "Value Engineering"	Searched all fields	136	2	0		
125	18/06/2019	10:48	10:49	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Kaizen" AND "Value Methodology"	Searched all fields	13	1	0		
126	18/06/2019	10:51	10:51	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Kaizen" AND "Value Management"	Searched all fields	31	0	0		
127	18/06/2019	10:54	10:54	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Kaizen" AND "Value Analysis"	Searched all fields	15	1	0		
128	18/06/2019	10:55	10:55	1955 - 18/06/2019	Free-text Searching	WorldCat Dissertations and Theses	1955 - 18/06/2019	"Kaizen" AND "Value Engineering"	Searched all fields	21	0	0		

Table 47: DATAD Search Methods and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
129	19/06/2019	10:29	10:29	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Toyota Production System" AND "Value Methodology"	Searched subject and applied "subject contains" filter	21	1	0	**0**	**0**
130	19/06/2019	10:42	10:44	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Toyota Production System" AND "Value Analysis"	Searched subject and applied "subject contains" filter	26	4	0		
131	19/06/2019	10:47	10:48	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Toyota Production System AND "Value Management"	Searched subject and applied "subject contains" filter	43	4	0		
132	19/06/2019	10:58	10:59	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Toyota Production System" AND "Value Engineering"	Searched subject and applied "subject contains" filter	22	4	0		
133	19/06/2019	11:02	11:03	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Lean" and "Value Methodology"	Searched subject and applied "subject contains" filter	2	2	0		
134	19/06/2019	11:04	11:04	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Lean" AND "Value Analysis"	Searched subject and applied "subject contains" filter	2	2	0		
135	19/06/2019	11:05	11:05	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Lean" AND "Value Management"	Searched subject and applied "subject contains" filter	2	2	0		
136	19/06/2019	11:07	11:07	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Lean" AND "Value Engineering"	Searched subject and applied "subject contains" filter	2	2	0		
137	19/06/2019	11:09	11:10	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"CI" AND "Value Methodology"	Searched subject and applied "subject contains" filter	2	1	0		
138	19/06/2019	11:13	11:14	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"CI" AND "Value Management"	Searched subject and applied "subject contains" filter	6	2	0		
139	19/06/2019	11:18	11:19	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"CI" AND " Value Analysis"	Searched subject and applied "subject contains" filter	3	2	0		
140	19/06/2019	11:20	11:20	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"CI" AND "Value Engineering"	Searched subject and applied "subject contains" filter	3	2	0		
141	19/06/2019	11:22	11:28	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Kaizen" AND "Value Methodology"	Searched subject and applied "subject contains" filter	0	0	0		
142	19/06/2019	11:28	11:28	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Kaizen" AND "Value Management"	Searched subject and applied "subject contains" filter	0	0	0		
143	19/06/2019	11:29	11:29	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Kaizen" AND "Value Analysis"	Searched subject and applied "subject contains" filter	0	0	0		
144	19/06/2019	11:32	11:32	All dates	Free-text Searching	Digital Archives of Theses and Dissertations (Current & Completed)	All dates	"Kaizen" AND "Value Engineering"	Searched subject and applied "subject contains" filter	0	0	0		

Table 48: Google Scholar Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
145	20/06/2019	06:48	06:50	All dates	Free-text Searching	Google Scholar	All dates	"Toyota Production System" AND "Value Methodology"	Advanced searched anywhere in the article	130	28	9		
146	20/06/2019	07:07	07:08	All dates	Free-text Searching	Google Scholar	All dates	"Toyota Production System" AND "Value Analysis"	Advanced searched anywhere in the article	3440	13	4		
147	20/06/2019	07:20	07:21	All dates	Free-text Searching	Google Scholar	All dates	"Toyota Production System AND "Value Management"	Advanced searched anywhere in the article	1620	7	6		
148	20/06/2019	07:30	07:31	All dates	Free-text Searching	Google Scholar	All dates	"Toyota Production System" AND "Value Engineering"	Advanced searched anywhere in the article	2520	6	1		
149	20/06/2019	07:45	07:45	All dates	Free-text Searching	Google Scholar	All dates	"Lean" and "Value Methodology"	Advanced searched anywhere in the article	341	13	8		
150	20/06/2019	08:10	08:12	All dates	Free-text Searching	Google Scholar	All dates	"Lean" AND "Value Analysis"	Advanced searched anywhere in the article	7530	16	4		
151	20/06/2019	08:24	08:26	All dates	Free-text Searching	Google Scholar	All dates	"Lean" AND "Value Management"	Advanced searched anywhere in the article	5380	17	6		
152	20/06/2019	08:37	09:39	All dates	Free-text Searching	Google Scholar	All dates	"Lean" AND "Value Engineering"	Advanced searched anywhere in the article	6470	19	9		
153	20/06/2019	08:58	09:00	All dates	Free-text Searching	Google Scholar	All dates	"CI" AND "Value Methodology"	Advanced searched anywhere in the article	1270	21	7	**82**	**29**
154	20/06/2019	09:36	09:36	All dates	Free-text Searching	Google Scholar	All dates	"CI" AND "Value Management"	Advanced searched anywhere in the article	15200	5	2		
155	20/06/2019	09:46	09:47	All dates	Free-text Searching	Google Scholar	All dates	"CI" AND " Value Analysis"	Advanced searched anywhere in the article	32500	11	4		
156	20/06/2019	10:09	10:11	All dates	Free-text Searching	Google Scholar	All dates	"CI" AND "Value Engineering"	Advanced searched anywhere in the article	15700	13	5		
157	20/06/2019	10:28	10:28	All dates	Free-text Searching	Google Scholar	All dates	"Kaizen" AND "Value Methodology"	Advanced searched anywhere in the article	44	7	3		
158	20/06/2019	10:37	10:38	All dates	Free-text Searching	Google Scholar	All dates	"Kaizen" AND "Value Management"	Advanced searched anywhere in the article	604	10	4		
159	20/06/2019	11:14	11:17	All dates	Free-text Searching	Google Scholar	All dates	"Kaizen" AND "Value Analysis"	Advanced searched anywhere in the article	1530	9	5		
160	20/06/2019	12:03	12:04	All dates	Free-text Searching	Google Scholar	All dates	"Kaizen" AND "Value Engineering"	Advanced searched anywhere in the article	1430	15	5		

Table 49: SAVE International Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
161	21/06/2019	10:46	11:17	45th Annual Conference: Manage Value	Manual Searching	SAVE International Website/Conference Page	Proceedings 2005	Lean (and synonyms) and Value Engineering (and synonyms)	Go to: SAVE International Website. Hover over: Conferences. Click: Past Conferences. Directed to: SAVE Past Conferences Webpage. Scroll down to: Oldest annual conference with link to proceedings. Click: Order proceedings. Redirected to: Conferences Proceedings.com> Browse by publisher>SAVE International. See: 14 SAVE International Conference Products for sale. Click: SAVE International Annual Conference 2005/2006/2007/2008/2009/2010/2011/2012/2013/2014/2015/2016/2017/2018. See: Product Description. Click View Table of Contents. Download. Manual Search of Conference Papers by Title	42	3	3	**14**	**14**
162	21/06/2019	11:24	11:29	46th Annual Conference: Manage Projects to Maximize Value	Manual Searching	SAVE International Website/Conference Page	Proceedings 2006			39	2	2		
163	21/06/2019	11:31	11:35	47th Annual Conference: Achieving Value Through Innovation	Manual Searching	SAVE International Website/Conference Page	Proceedings 2007			35	0	0		
164	21/06/2019	11:36	11:43	48th Annual Conference: Discovering Value Added Strategies	Manual Searching	SAVE International Website/Conference Page	Proceedings 2008			26	0	0		
165	21/06/2019	11:46	11:49	49th Annual Conference: SAVE at 50: Celebrating Our Past, Driving Future Value	Manual Searching	SAVE International Website/Conference Page	Proceedings 2009			32	0	0		
166	21/06/2019	11:50	11:55	50th Annual Conference: Join Us for a Value Adventure on the High Seas	Manual Searching	SAVE International Website/Conference Page	Proceedings 2010			30	1	1		
167	21/06/2019	12:01	12:05	51st Annual Conference: Value at the Trail's End	Manual Searching	SAVE International Website/Conference Page	Proceedings 2011			41	2	2		
168	21/06/2019	12:08	12:14	52nd Annual Conference:	Manual Searching	SAVE International Website/Conference Page	Proceedings 2012			42	1	1		
169	21/06/2019	12:16	12:20	SAVE 2013 Value Summit	Manual Searching	SAVE International Website/Conference Page	Proceedings 2013			28	0	0		
170	21/06/2019	12:20	12:25	SAVE 2014 Value Summit	Manual Searching	SAVE International Website/Conference Page	Proceedings 2014			32	2	2		
171	21/06/2019	12:26	12:29	SAVE 2015 Value Summit	Manual Searching	SAVE International Website/Conference Page	Proceedings 2015			24	1	1		
172	21/06/2019	12:31	12:36	SAVE/VAC 2016 Value Summit: The Power of VE	Manual Searching	SAVE International Website/Conference Page	Proceedings 2016			48	1	1		
173	21/06/2019	12:38	12:44	SAVE 2017 Value Summit	Manual Searching	SAVE International Website/Conference Page	Proceedings 2017			47	0	0		
174	21/06/2019	12:45	12:47	SAVE 2018 Value Summit	Manual Searching	SAVE International Website/Conference Page	Proceedings 2018			34	0	1		

Table 50: HKIVM Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
175	21/06/2019	21:30	21:37	Hong Kong Institute of Value Management International Conference 2000: Add Value,	Manual Searching	HKIVM Website/ Conferences Page	Proceedings 2000	Lean (and synonyms) and Value Engineering (and synonyms)	HKIVM Website. Click: Conferences. Scroll down: find the oldest conference which includes an agenda.	19	0	0	1	1
176	21/06/2019	21:40	21:45	Hong Kong Institute of Value Management International Conference 2010	Manual Searching	HKIVM Website/ Conferences Page	Proceedings 2010	Lean (and synonyms) and Value Engineering (and synonyms)	Click Conference Proceedings details. View paper tiles. Search for relevant papers by title.	13	0	0		
177	21/06/2019	21:52	21:56	Hong Kong Institute of Value Management International Conference 2005	Manual Searching	Proceedings.com Website/ Hong Kong Institute of Value Management Ltd Product Webpage	Proceedings 2005	Lean (and synonyms) and Value Engineering (and synonyms)	Go to: Conference Proceedings.com Website. Click: Browse by publisher. Search: Honk Kong Institute of VM. See: Conference proceedings. View: table of Contents. Search for relevant conferenec paper by title.	23	0	0		
178	21/06/2019	21:56	21:29	Hong Kong Institute of Value Management International Conference 2006	Manual Searching	Proceedings.com Website/ Hong Kong Institute of Value Management Ltd Product Webpage	Proceedings 2006	Lean (and synonyms) and Value Engineering (and synonyms)		30	0	0		
179	21/06/2019	21:59	22:04	Hong Kong Institute of Value Management International Conference 2012	Manual Searching	Proceedings.com Website/ Hong Kong Institute of Value Management Ltd Product Webpage	Proceedings 2012	Lean (and synonyms) and Value Engineering (and synonyms)		23	1	1		

Table 51: IVM Australia Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
180	21/06/2019	22:17	22:20	All dates	Manual Searching	Institute of Value Management Australia Website/ Member Papers Webpage	All dates	Lean (and synonyms) and Value Engineering (and synonyms)	Go to: Institute of Value Management Australia Website. Click: The Knowledge Bank. Click: Member Papers. Search by title	20	0	0	0	0
181	21/06/2019	22:25		All dates	Manual Searching	Institute of Value Management Australia Website/ Member Papers Webpage	All dates	Lean (and synonyms) and Value Engineering (and synonyms)	Go to: Institute of Value Management Australia Website. Click: The Knowledge Bank. Click: Member Papers. Search by title	44	0	0		

Table 52: Lean Institute Search Method and Results

Item Number	Date	Start Time	End Time	Search coverage dates	Search Type	Database	Database coverage dates/ isssue	Search Terms	Search Strategy Description	Number of Records Retrieved	Number of Records Selected By Title	Number of Records Selected by Abstract	Total Records Selected by Abstract	Number of Records Selected after intra-source deduplication
182	23/06/2019	08:07	08:20	Lean Africa Summit 2018/2019	Manual Searching	Lean Africa Website/ Summit Webpage	Summit proceedings 2018/2019	Lean (and synonyms) and Value Engineering (and synonyms)	Go to: Lean Institute Africa Website. Click Lean Summit. Redirected to: Lean Summit Webpage. Scroll Down: oldest Summit with programme. Click Summit programme. Manual Search: Summit Papers by Titles	36	0	0	**0**	**0**
183	21/06/2019	08:07	08:20	All fdates	Manual Searching	Lean Africa Website/ Knowledge Center Webpage	All dates	Lean (and synonyms) and Value Engineering (and synonyms)	Go to: Lean Institute Africa Website. Click Lean Summit. Redirected to: Knowledge Center Webpage. Search for published research or conferences papers	0	0	0		
184	21/06/2019	08:20	08:25	All dates	Manual Searching	Lean Global Website/ Publications Webpage	All dates	Lean (and synonyms) and Value Engineering (and synonyms)	Go to: Leanglobal.org Website. Click: What we do. Click: Publications. Search: Research or Conference papers	0	0	0		

Appendix 1-B: Bibliographic Searching Results

Table 53: Bibliographic Searching Method and Results

Seed Article Number	Seed Article Author	Year	Seed Article Title	Search Date	Number of articles retrieved	Number of articles selected by title	Number of articles selected after duplicated removed	Number of articles selected by abstract (articles selected for Full Text Reading)
1	Borgianni et al	2010	Process value analysis for business process re-engineering	28/06/2019 - 05/08/2019	81	3	3	0
2	Cell & Arratia	2003	Creating value with Lean thinking and Value Engineering	28/06/2019 - 05/08/2019	0	0	0	0
3	Chakravartty	1991	Value Analysis and Value Engineering as a cost reduction tool and its relation with JIT manufacturing	28/06/2019 - 05/08/2019	25	0	0	0
4	de Hemmer	2012	Value(s) and management: There's value everywhere!	28/06/2019 - 05/08/2019	16	0	0	0
5	Ekanayake & Sandanayak	2017	LiVE approach: Lean integrated Value Engineering for construction industry	28/06/2019 - 05/08/2019	29	6	1	0
6	Ho et al	2000	Integration of Value Analysis and Total Quality Management: The way ahead in the next millennium	28/06/2019 - 05/08/2019	17	0	0	0
7	Kheradia	2011	TALEVAS model: an integrated quality methodology	28/06/2019 - 05/08/2019	79	2	0	0
8	Lee et al	2016	Using ICT to Improve Service Quality	05/08/2019	18	0	0	0
9	Lehman & Reiser	2004	Maximizing value & minimizing waste: Value Engineering & Lean Construction	28/06/2019 - 05/08/2019	0	0	0	0
10	Mandelbaum et al	2010	Value Engineering Synergies With Lean Six Sigma	28/06/2019 - 05/08/2019	55	3	1	1
11	Musa et al	2016	Where Lean construction and Value Management meet	28/06/2019 - 05/08/2019	47	9	2	0
12	Nassey	2004	Implementation of Lean method and Value Analysis in the sandblasting production shop at Intersign Corporation	28/06/2019 - 05/08/2019	23	0	0	0
13	Nayak	2006	Lean Manufacturing and Value Management convergence of divergent tools	28/06/2019 - 05/08/2019	23	7	3	2
14	Odedairo & Bell	2010	Framework for introducing and implementing value methods: a novel toolkit for small and medium scale industries in developing nations	28/06/2019 - 05/08/2019	21	1	1	0
15	Ogunbiyi et al	2011	Innovative Value Management: assessment of Lean Construction implementation	28/06/2019 - 05/08/2019	58	6	1	0
16	Parker	2015	Lean as a value enhancing methodology	05/08/2019	6	0	0	0
17	Prahladalaj	2004	Integration of Lean Manufacturing and Value Engineering techniques to improve the internal distribution system in a manufacturing company	28/06/2019 - 05/08/2019	19	0	0	0
18	Sacadura & Tenera	2011	Integrating Value and Lean Management in manufacturing processes	28/06/2019 - 05/08/2019	13	0	0	0
19	Salvatierra-Garrido et al	2008	Social housing in Chile: Opportunities to apply value concept in early stage of projects	28/06/2019 - 05/08/2019	21	1	0	0
20	Shekari & Fallahian	2007	A new approach to linking Value Engineering & Lean Methodology	28/06/2019 - 05/08/2019	7	1	1	
21	Thorsen	2005	Value Stream Mapping & VM	28/06/2019 - 05/08/2019	2	0	0	0
22	Watson	2005	Putting value back into engineering	28/06/2019 - 05/08/2019	0	0	0	0
23	Wixson	2005	A Value Management Approach to Improving Quality Performance	28/06/2019 - 05/08/2019	5	1	1	1
24	Wohnhas	2014	Value Management in Lean product development	28/06/2019 - 05/08/2019	0	0	0	0
					565	40	14	4

Appendix 1-C: Citation Searching Results

Table 54: Citation Searching Method and Results

Seed Article Number	Seed Article Author	Year	Seed Article Title	Search Date	Number of records retrieved	Number of articles selected by title	Number of articles selected after duplicates removed	Number of articles selected by abstract (artciles selected for Full Text Reading)
1	Borgianni et al	2010	Process value analysis for business process re-engineering	28/06/2019 - 05/08/2019	21	1	1	1
2	Cell & Arratia	2003	Creating value with Lean thinking and Value Engineering	28/06/2019 - 05/08/2019	14	5	0	0
3	Chakravartty	1991	Value Analysis and Value Engineering as a cost reduction tool and its relation with JIT manufacturing	28/06/2019 - 05/08/2019	0	0	0	0
4	de Hemmer	2012	Value(s) and management: There's value everywhere!	28/06/2019 - 05/08/2019	0	0	0	0
5	Ekanayake & Sandanayake	2017	LiVE approach: Lean integrated Value Engineering for construction industry	28/06/2019 - 05/08/2019	3	0	0	0
6	Ho et al	2000	Integration of Value Analysis and Total Quality Management: The way ahead in the next millennium	28/06/2019 - 05/08/2019	34	0	0	0
7	Kheradia	2011	TALEVAS model: an integrated quality methodology	28/06/2019 - 05/08/2019	11	0	0	0
8	Lee et al	2016	Using ICT to Improve Service Quality	28/06/2019 - 05/08/2019	0	0	0	0
9	Lehman & Reiser	2004	Maximizing value & minimizing waste: Value Engineering & Lean Construction	28/06/2019 - 05/08/2019	21	1	0	0
10	Mandelbaum et al	2010	Value Engineering Synergies With Lean Six Sigma	28/06/2019 - 05/08/2019	2	1	1	0
11	Musa et al	2016	Where Lean construction and Value Management meet	28/06/2019 - 05/08/2019	1	0	0	0
12	Nassey	2004	Implementation of Lean method and Value Analysis in the sandblasting production shop at Intersign Corporation	28/06/2019 - 05/08/2019	0	0	0	0
13	Nayak	2006	Lean Manufacturing and Value Management convergence of divergent tools	28/06/2019 - 05/08/2019	7	1	0	0
14	Odedairo & Bell	2010	Framework for introducing and implementing value methods: a novel toolkit for small and medium scale industries in developing nations	28/06/2019 - 05/08/2019	10	0	0	0
15	Ogunbiyi et al	2011	Innovative Value Management: assessment of Lean Construction implementation	28/06/2019 - 05/08/2019	6	1	0	0
16	Parker	2015	Lean as a value enhancing methodology	28/06/2019 - 05/08/2019	0	0	0	0
17	Prahladalaj	2004	Integration of Lean Manufacturing and Value Engineering techniques to improve the internal distribution system in a manufacturing company	28/06/2019 - 05/08/2019	0	0	0	0
18	Sacadura & Tenera	2011	Integrating Value and Lean Management in manufacturing processes	28/06/2019 - 05/08/2019	5	0	0	0
19	Salvatierra-Garrido et al	2008	Social housing in Chile: Opportunities to apply value concept in early stage of projects	28/06/2019 - 05/08/2019	4	2	0	0
20	Shekari & Fallahian	2007	A new approach to linking Value Engineering & Lean Methodology	28/06/2019 - 05/08/2019	1	1	0	0
21	Thorsen	2005	Value Stream Mapping & VM	28/06/2019 - 05/08/2019	9	0	0	0
22	Watson	2005	Putting value back into engineering	28/06/2019 - 05/08/2019	7	0	0	0
23	Wixson	2005	A Value Management Approach to Improving Quality Performance	28/06/2019 - 05/08/2019	4	0	0	0
24	Wohnhas	2014	Value Management in Lean product development	28/06/2019 - 05/08/2019	0	0	0	0
					160	13	2	1

Appendix 2: Critical Appraisal Analysis

Table 55: Borgianni et al. (2010) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: Design of a new methodology to achieve value delivery and support Business Process Re-engineering activities. All themes are relevant to Lean and Value Engineering but the methodology is purposed for products and services.	2	3	67%
	2	Discipline	Mechanical Engineering: this is a branch of engineering that involves design, construction, operation, maintenance of machinery and is applied in various disciplines. The audience targeted is one that exists in a mature industry where the company seeks new demand/market opportunities. It is important to note that not all industries are mature.	2	3	
	3	Context	The Italian footwear industry: the Italian footwear industry is the 7th largest exporter of footwear in the world, however this study was based on a certain sector of this industry. This study was also focused on mature industries only.	2	3	
	4	Strength of Recommendations	The recommended method is suitable for the manufacturing industry but was applied in a specific sector of the footwear industry. The proposed methodology was not presented as a Lean and VE hybrid methodology but features an amalgamated use of a few Lean and VE components. Not all aspects of Lean and VE were applied in the recommended model, only Gemba, JIT, value equation and function analysis are applied. The recommendations were made for mature industries seeking new demand. The recommendations were based on an analysis of various factories using technical reports and industry experts; the number of reports and the number of experts were not specified.	2	3	
Validity	5	Author	Author Y Borgianni is a Researcher and appears in 86 articles on Google Scholar; the articles have been cited 398 times. G Cascini is a Professor and appears in 442 articles on Google Scholar; the articles have been cited 1171 times. F Rotini is an Assistant Professor and appears in 124 articles on Google Scholar; the articles have been cited 721 times.	3	3	63%
	6	Literature Source	Journal of Engineering Manufacture produced by the Institute of Mechanical Engineers.	3	3	
	7	Study Design	Qualitative: Literature Review, Case Study	2	3	
	8	Sample Suitability	The sample was the accessible footwear within the Italian footwear industry. Specifically, various factories were analysed using technical reports and industry experts, but the number of reports and number of experts were unspecified.	1	3	
	9	Data Collection Methods	Analysis of technical publications and Interviews with experts that have 20 years experience	2	3	
	10	Data Analysis Methods	A literature review was used to generate the model and the Case Study method was utilised to validate the model.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	This study is motivated by an argument that the current BPR methodologies were not suitable for creating new market demand/opportunities. The purpose was to propose a new methodology suitable for application within mature industries which are highly competitive. Claims were made that current BPR methods have been unsuccessful but the reasons are not sufficiently explored. Additional claims were made that current BPR methods did not effectively increase customer value, this claim was also not sufficiently supported. Counter Evidence was not explored. A literature review of various BPR methods was conducted. The concepts were presented using a clear and logical structure. The theoretical foundations of the proposed methods were not explored exhaustively. The proposed model was validated using a case study. The model was tested in the footwear industry context for mature markets. The authors also provided example where the methods had been tested in walking device assists industry and in biofuel production. The study limitations were associated with organisational and consumer readiness uncertainty.	2	3	
	12	Overall Aim to minimise bias	The proposed method was applied using Case Study method for validation purposes. However the methods used to minimise bias were not specified	0	3	
Reproducibility	13	Data Collection Methods	The authors did not provide a reference list of the technical data that was analysed; they did not give a detailed list of the experts that were interviewed nor did they summarise a description of the interview questionnaire.	0	3	55%
	14	Number of Factors Explored	The authors mentioned that they reviewed several technical reports and interviewed various experts but exact numbers are not presented. The authors validated the method using data from various factories in the footwear industry, they also provided examples of the method application in two other industries.	2	3	
	15	Number of Studies Explored	The authors reviewed literature of various BPR methods, and they reviewed literature detailing previous developments of hybrid or amalgamated methods similar to the method they proposed. However, they did not review previous Lean and VE hybrid methodology literature.	2	3	
	16	Data Analysis Methods	The authors do not provide a reference list of the technical data that was analysed; they did not give a detailed list of the experts that were interviewed. The authors did provide a detailed description of the method validation case study.	1	3	
Borgianni et al (2010): Process value analysis for Business Process Re-engineering				**28**	**48**	**58%**

Table 56:Cell & Arratia (2003) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and the abstract contain the following themes: The use of Lean and VE in a collaborative and synergistic manner to affect cost, value, organisational culture, productivity and customer relations. The theme involves an integration of Lean and VE in their entirety, this is not limited to any specific context.	3	3	
	2	Discipline	The study discipline is Industrial Engineering, specifically the Lean and Value Engineering aspects of the discipline. This study was presented at the SAVE international conference and was intended for Lean and VE practitioners and analysts. Industrial Engineering is a disciplined that is applied various other disciplines.	3	3	83%
	3	Context	This study is a conceptual paper and therefore was not conducted in a specific environment.	3	3	
	4	Strength of Recommendations	The recommendations were proposed for all organisations. The recommendations were made in a broad context without addressing context specific limitations. They were based on expert opinion, facts, explanations, arguments and logical reasoning; these are common analysis methods of conceptual papers. The recommendations were not based on an analysis of previous literature that investigated the application of similar Lean integrated VE models.	1	3	
Validity	5	Author	C Cell is a Value Engineering Programme Manager for the U.S army. B Arratia is a Lead for Lean initiatives in the U.S army. They both authors hold Bachelor and Masters degrees and are Lean and VE practitioners.	3	3	
	6	Literature Source	Society of American Value Engineers (SAVE) Conference, published by SAVE International	2	3	
	7	Study Design	Qualitative: Conceptual paper	1	3	
	8	Sample Suitability	The sample data (literature) size, type and characteristics were not specified. The data used in this study was literature.	1	3	
	9	Data Collection Methods	The data (literature) collection methods were not specified.	0	3	
	10	Data Analysis Methods	Content Analysis was used. Expert opinion, facts, explanations, logical reasoning was used to analyse the data.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The paper was motivated by the argument that Lean and VE have certain limitations when applied separately, these can be overcome by collaborative implementation. The purpose of the paper was to present the concept of Lean and VE hybrid methodology, where Lean and VE can be applied collaboratively to achieve synergistic benefits. Various claims were made that Lean and VE have certain weaknesses and strengths; these are supported by examples. The main claim made was that the combined application of Lean and VE can result in synergistic benefits. The claims were supported by facts, explanations, expert opinion and logical reasoning. Counter evidence was not addressed sufficiently, the authors claim that there is no conflict between Lean and VE. Lean and VE literature was discussed but not referenced; previous similar research was not referenced. The paper was presented in a clear structure. The theoretical foundation was based on expert opinion, facts and explanations. The assertations made are not supported by empirical evidence. Limitations were not addressed nor were the implications for future research.	1	3	42%
	12	Overall Aim to minimise	The bias minimization methods were not discussed.	0	3	
Reproducibility	13	Data Collection Methods	The data (literature) collection methods were not specified.	0	3	
	14	Number of Factors Explored	The authors presented Lean and VE literature suitable for the arguments made. However, not all aspects of Lean and VE literature were explored. Previous similar literature was not referenced.	1	3	25%
	15	Number of Studies	There was review of Lean and VE literature but no review of literature that proposed the combined application of Lean and VE.	1	3	
	16	Data Analysis Methods	The arguments were presented in a manner that allowed the reader to assess the soundness of the arguments. However, there was no reference list for	1	3	
Cell & Arratia (2003): Creating value with Lean thinking and Value Engineering				23	48	**48%**

Table 57:Chakravartty (1991) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and the abstract contain the following themes: Value Engineering and Just In Time (JIT, a Lean technique) integration for the purposes of cost reduction and quality improvement. The themes refer to VE in its entirety but refer to a component of Lean and all efforts are focused on cost reduction and quality improvement.	2	3	
	2	Discipline	The study is conducted within the discipline of Industrial Engineering, Industrial Engineering principles are applicable to various other disciplines.	3	3	
	3	Context	The study was conducted in the Manufacturing environment, specifically in the manufacturing of household air diffusers.	1	3	58%
	4	Strength of Recommendations	The recommendations made were based on a case study application in one company. The case study involved the application of VE in the redesign of one product. JIT is recommended but is not applied in the case study and thus it was not proven how the combined effect of VE and JIT results in enhancement of continuous improvement initiatives.	1	3	
Validity	5	Author	U Chakravartty completed this study to obtain an MSc in Industrial Engineering.	2	3	
	6	Literature Source	The University of Texas at El Paso published by ProQuest	3	3	
	7	Study Design	Qualitative: Case Study	1	3	
	8	Sample Suitability	The sample was a company that manufactures air diffusers. The size of the company was not specified.	1	3	
	9	Data Collection Methods	VE data collection methods were utilised, various company personnel were interviewed.	2	3	
	10	Data Analysis Methods	VE methods were used to analyse the collected data, this methods includes qualitative and quantitative analysis.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The motivation of this study was a need to explore the application of Industrial Engineering tools in cost reduction activities. The purpose of the study was to show the benefits of the combined implementation of VE and JIT through the application of a case study method. The main claim that was made was that VE and JIT are "twins" and their combined application results in increased benefits, when VE is applied to product design and JIT is applied to the manufacturing process. No counter evidence was explored. Both VE and JIT literature was reviewed; however, no literature that proposes the combined application of Lean and JIT was reviewed. The research was presented using a clear structure and logical flow. The theoretical foundation of VE and JIT amalgamation was discussed briefly. The study itself only showed the application of VE, the author simply recommended that JIT must be applied after VE has been applied. All data was collected and analysed using VE methods. Study limitations were discussed with some recommendations for future research.	1	3	50%
	12	Overall Aim to minimise bias	The paper did not include explicit details highlighting the methods used to minimise bias.	0	3	
Reproducibility	13	Data Collection Methods	Data collection methods were not described explicitly in a manner that facilitates auditability. However, it is evident that VE methods are used for data collection.	1	3	
	14	Number of Factors Explored	Various factors were explored for the purposes of investigating the effects of VE in air diffuser product redesign. However, little data was provided to substantiate the complementary effects of VE and JIT.	1	3	
	15	Number of Studies Explored	There was no review of previous literature that describes the effects of combined VE and JIT; the author did not mention whether such literature existed or not.	2	3	50%
	16	Data Analysis Methods	The data analysis methods (VE methods) were stated clearly enough to facilitate auditability. However, there was minimal data analysis conducted to substantiate the effect of combining VE and JIT.	2	3	
Chakravartty (1991): Value Analysis and Value Engineering as a cost reduction tool and its relation with JIT manufacturing				25	48	**52%**

Table 58: de Hemmer (2012) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: The combining of various methods that are utilised to manage value, this includes Lean and VE. The integration contained in the theme is purposed for value management objectives only.	2	3	67%
	2	Discipline	The study was focused on value management methods that often fall under the Industrial Engineering discipline. Industrial Engineering can be applied to all other disciplines.	3	3	
	3	Context	The study is not set in any particular environment but is aimed at enhancing several methods that are utilised to manage value.	2	3	
	4	Strength of Recommendations	Brief analyses (expert opinion, explanations, logical reasoning, literature review) were conducted to propose the implementation Lean and VE in a synergistic manner. Minimal Lean and VE literature was reviewed.	1	3	
Validity	5	Author	O de Hemmer wrote the paper while completing a PhD at the Hong Kong Polytechnic University; this article was reviewed by various Doctors and Professors within the university.	3	3	38%
	6	Literature Source	The International Conference on Value Engineering and Management organised by the Hong Kong Polytechnic University. Literature was published on the university's website.	2	3	
	7	Study Design	Qualitative: Conceptual Paper	1	3	
	8	Sample Suitability	The author sampled literature. Minimal Lean and VE literature was analysed. The literature did not include similar literature which described Lean and VE integration.	1	3	
	9	Data Collection Methods	The methods utilised to collect the data (literature) were not specified	0	3	
	10	Data Analysis Methods	Brief analyses (expert opinion, explanations, logical reasoning, literature review) were conducted to propose the implementation Lean and VE in a synergistic manner.	1	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	This paper was motivated by an argument that there was no "legitimate" method that could be utilised to manage value. The purpose of the paper was to propose a "legitimate" method to manage value using combined improvement methods. The term "legitimate" is not defined, the motivating argument was not sufficiently substantiated, no explanations were provided to show that no legitimate method existed. There was minimal evidence provided to support the suitability of Lean and VE amalgamation. Lean and VE literature was reviewed briefly but there is no review of previous literature that discuses the combining of Lean and VE. The paper was presented in a clear structure showing a logical flow of ideas. Data was analysed using arguments, logical reasoning and brief explanations. The concluding remarks included recommendations for implementation in organisations, while limitations and implications for future research were not discussed.	1	3	
	12	Overall Aim to minimise bias	Bias minimization methods were not explicitly discussed.	0	3	
Reproducibility	13	Data Collection Methods	The data (literature) collection methods were not specified.	0	3	25%
	14	Number of Factors Explored	Minimal Lean and VE data was reviewed.	1	3	
	15	Number of Studies Explored	Minimal Lean and VE Literature was reviewed	1	3	
	16	Data Analysis Methods	The arguments were presented in a manner that allows the reader to test for soundness. There was inconsistent referencing, this impedes auditability.	1	3	
De Hemmer (2012): Value(s) and management: There's value everywhere!				20	48	**42%**

Table 59: Ekanayake & Sandanayake (2017) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and the abstract contain the following themes: Lean and Value Engineering integration to achieve synergy within the construction industry. The study is limited to the construction context.	2	3	75%
	2	Discipline	Construction sector. Construction projects involve various disciplines such as Civil Engineering, Project Management, Safety/Health/Environmental	3	3	
	3	Context	The Construction Industry in Sri Lanka. This industry contributes 7% to the Sri Lankan GDP.	2	3	
	4	Strength of Recommendations	The recommendations were specific to the construction industry and were based on Literature Review, Content Analysis and Expert consultation. The experts had combined industry experience that amounted to 140 years. The proposed method was not tested.	2	3	
Validity	5	Author	Ekanayake is a PhD fellow at the Hong Kong Polytechnic University who appears in 9 Google Scholar articles that have been cited 5 times. Sandanayake is a Senior Lecturer who appears in 77 Google Scholar articles that have been cited 143 times.	3	3	79%
	6	Literature Source	Built Environment and Asset Management Journal published by Emerald Insight.	3	3	
	7	Study Design	Qualitative: Literature Survey, Unstructured Interviews (Expert opinion)	2	3	
	8	Sample Suitability	The literature survey was an analysis of 4 articles that discuss Lean and VE integration. The unstructured interviews were conducted with six industry experts	2	3	
	9	Data Collection Methods	The literature collection method was not specified, there was no evidence of the use of systematic literature review data collection methods. The	2	3	
	10	Data Analysis Methods	A code-based Content Analysis method with NVivo software	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	This study was motivated by the argument that previous literature involved the proposal of Lean integrated VE in general organisations and manufacturing but no research existed that explored the implementation of integrated methods in the construction industry. The purpose of the research was to develop Lean integrated VE synergy concepts suitable for implementation in the construction industry. Claims were made that such a study had not been conducted in the construction industry, this claim was supported. Another major claim was that Lean and VE can be suitably combined to achieve synergy and this was supported by literature as well as industry expert opinion. The study contained a literature review of individual Lean and VE concepts as well as a review of research which explores Lean integrated VE. The research was presented using a structured approach and logical flow. The theoretical foundation for Lean and VE integration was presented using a comparative analysis of the two methodologies. Literature data was analysed using arguments, explanations, logical reasoning, facts and expert opinion. The study limitations were not discussed, the proposed method was recommended for the construction industry. The authors recommend future research to focus on tool selection methods for Lean and VE integration models.	3	3	
	12	Overall Aim to minimise bias	The authors did not explicitly declare methods used to minimise bias, However, they mentioned the use of Purposive sampling (researcher judgement used to obtain a representative sample); and they mentioned the use of code-based content analysis.	2	3	
Reproducibility	13	Data Collection Methods	The collection of data for the literature survey was not conducted using transparent methods. The authors described the way in which the expert opinion data was collected	2	3	75%
	14	Number of Factors Explored	The authors explored 4 research papers and consulted 6 industry experts with a total of 140 years experience.	2	3	
	15	Number of Studies Explored	The authors explored Lean and VE literature and Lean and VE hybrid methodology literature. They did not explore any empirical literature.	2	3	
	16	Data Analysis Methods	Data analysis methods were explicit	3	3	
Ekanayake & Sandanayake (2017): LiVE approach: Lean integrated Value Engineering for construction industry				37	48	**77%**

Table 60: Ho et al. (2000) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The themes contained in the title and abstract are as follows: the integration of Value Engineering and Total Quality Management (TQM- a Lean technique/tool) to exhaust the full potential of TQM. VE is integrated with a component of Lean.	2	3	75%
	2	Discipline	This study was written by authors who belong to the Building and Real Estate department at Hong Kong Polytechnic University; and it was published in a TQM journal that falls under the Industrial Engineering Discipline. Therefore the two disciplines are Building and Real Estate as well as Industrial Engineering.	3	3	
	3	Context	This study was not set in a particular environment, but was conducted at the Hong Kong Polytechnic University. It is a conceptual paper that provided recommendations for organisations that apply TQM.	2	3	
	4	Strength of Recommendations	The recommendations were based on a comparative analysis of theoretical concepts of VE and TQM, however context-based empirical factors were not incorporated into the analysis or arguments. The recommendations were based on a literature review.	2	3	
Validity	5	Author	Ho D.C.K is affiliated with the Hong Kong Polytechnic University and appears in 20 research publications on Research Gate. Cheng E.W.L is affiliated with the Education University of Hong Kong and appears in 80 research publications on Research Gate. Fong P.S.W is affiliated with the Hong Kong Polytechnic University and appears in 2 books and 72 research articles on the Academia.edu website.	3	3	50%
	6	Literature Source	The research paper was published in the Total Quality Management and Business Excellence Journal, the full text was obtained from the Taylor and Francis database.	3	3	
	7	Study Design	Qualitative: Literature Review	2	3	
	8	Sample Suitability	VE and TQM theoretical and empirical literature was analysed and discussed. However, there is no discussion or review of previous similar literature that proposes VE and TQM integration.	1	3	
	9	Data Collection Methods	The literature collection methods were not described	0	3	
	10	Data Analysis Methods	Literature review methods were applied. The author presented facts, explanations and used logical reasoning and arguments to analyse the data.	1	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the argument that there was a need to enhance competitive advantage by improving the effectiveness and sustainability of TQM through integration with the VE method. The purpose of the study was to explore the common areas of VE and TQM in order to investigate and recommend integration opportunities of the two methods. The main claim made was that VE can assist in achieving customer satisfaction in TQM implementation; this claim was supported by an analysis of areas that are common and uncommon to TQM and VE. The arguments were presented in a clear structure with logical idea flow. The data was analysed using explanations, arguments, facts and logical reasoning. The limitations of the study were not discussed, however it was recommended that further research should be conducted to explore the integration of TQM with VE and other improvement tools.	2	3	
	12	Overall Aim to minimise bias	The bias minimization methods were not explicitly highlighted.	0	3	
Reproducibility	13	Data Collection Methods	The literature collection methods were not described	0	3	42%
	14	Number of Factors Explored	The authors explored TQM data and VE data but did not explore any previous data that included VE and TQM integration proposals; there was also no data on the potential integration barriers	1	3	
	15	Number of Studies Explored	The authors explored TQM literature and VE literature but did not explore similar previous literature; there was also no literature on the potential integration barriers	1	3	
	16	Data Analysis Methods	The arguments were presented clearly in a manner that facilitates auditability.	3	3	
Ho et al (2000): Integration of value analysis and total quality management: The way ahead in the next millennium				26	48	**54%**

Table 61: Kheradia (2011) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and the abstract contain the following themes: an integrated approach to quality management in any organisation through combining Lean, VE and other improvement methods. The proposed method is proposed for quality management purposes only.	2	3	75%
	2	Discipline	The study focused on quality management and has been published in a TQM journal; TQM is a technique that is associated with the Industrial Engineering Discipline. Industrial Engineering is applied to various other disciplines.	3	3	
	3	Context	The study focused on quality management. The author asserted that the proposed method is suitable to organisation in any sector and to organisations of all sizes. The paper is conceptual and is thus not limited to any particular environment.	3	3	
	4	Strength of Recommendations	The recommendations were based on analyses of theoretical concepts of quality management, VE, Lean and other improvement concepts. Context-based empirical factors were not incorporated into the analyses or arguments, the presented theory was based on systems thinking, "seven rules of quality driving" and the "theory of the rising pendulum".	1	3	
Validity	5	Author	A Kheradia holds BSc and MSc qualifications and 12 years experience in Food Science, Safety and Quality Assurance. He is affiliated with the University of Guelph in Canada and appears in three articles on the Emerald Insight database.	3	3	54%
	6	Literature Source	The paper is published in The Total Quality Management Journal, full text obtained from the Emerald Insight database	3	3	
	7	Study Design	Qualitative: Literature review, Conceptual paper	2	3	
	8	Sample Suitability	The sample was literature. VE, Lean, quality management, "theory of the rising pendulum" , "the seven rules of quality driving" and systems thinking literature was reviewed and analysed. There is also a discussion or review of previous literature that similarly proposes the integration of Lean and VE methods. The sample consisted of theoretical concepts only, empirical data was not reviewed.	2	3	
	9	Data Collection Methods	The methods used to collect the literature were not discussed.	0	3	
	10	Data Analysis Methods	The methods used to analyse the data and create the model were: "the theory of the rising pendulum" and "seven rules of driving quality". The author also used logical reasoning, facts, arguments and explanations to establish and propose this integrated model.	1	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the argument that there exists a need to develop a systems approach to quality management to facilitate organisational competitive advantage and improve customer focus. The purpose of the study was to develop and propose a quality management model that integrates Lean, VE and other improvement models. The main claim of the study is that a systematic and integrated approach to quality can improve competitive advantage, costs, value customer focus and other factors. This claim was supported by various facts, logical reasoning and explanations. The theoretical foundation of the model presented was "theory of the rising pendulum" and "seven rules of quality driving". The concepts and recommendations were presented in a structured and logical manner. The author highlighted that the proposed model was limited by four key performance drivers and was vulnerable to over-implication and hyper-analysis.	2	3	
	12	Overall Aim to minimise bias	The author did not explicitly mention methods used to minimise bias.	0	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not specified and therefore were not auditable	0	3	50%
	14	Number of Factors Explored	The sample was literature. VE, Lean, quality management, "theory of the rising pendulum" , "the seven rules of quality driving" and systems thinking literature was reviewed and analysed. There is also a discussion or review of previous literature that similarly proposes the integration of Lean and VE methods. The sample consisted of theoretical concepts only, empirical data was not reviewed.	2	3	
	15	Number of Studies Explored	The sample was literature. VE, Lean, quality management, "theory of the rising pendulum" , "the seven rules of quality driving" and systems thinking literature was reviewed and analysed. There is also a discussion or review of previous literature that similarly proposes the integration of Lean and VE methods. The sample consisted of theoretical concepts only, empirical data was not reviewed.	1	3	
	16	Data Analysis Methods	The arguments and analyses were both presented clearly in a manner which facilitates auditability	3	3	
Kheradia (2011): TALEVAS model: an integrated quality methodology				28	48	**58%**

Table 62: Lee et al. (2016) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: A VE based methods that involves the integration of Failure Mode and Effect Analysis (FMEA), Lean and Six Sigma to support the configuration of customer service centre and improve call-centre service quality.	2	3	75%
	2	Discipline	The research is within the Information and Communications Technology Discipline. The principles and techniques found in this discipline are applied in various other disciplines.	3	3	
	3	Context	The research was based in the service sector, specifically the call-centre and customer service environment. This service is utilised by many sectors to conduct customer engagement. The model presented is applied (via Case Study method) in the Manufacturing environment.	2	3	
	4	Strength of Recommendations	The study contained a recommendation of an integrated service quality model, this model was developed using analyses of the theoretical concepts of Lean, VE, FMEA and Six Sigma. The recommended model was validated via Case Study methodology.	2	3	
Validity	5	Author	L.J.H Lee is affiliated with the Taiwan National Central University, he appears in 6 articles on the IEEE Xplore digital library. Y.W Huang is affiliated with the Taiwan National Central University, he appears in 5 articles on the IEEE Xplore digital library. J.D Leu is affiliated with the Taiwan National Central University, he appears in 14 articles on the IEEE Xplore digital library.	3	3	63%
	6	Literature Source	This article was published in the International Journal of Electronic Business Management via ProQuest Central database	3	3	
	7	Study Design	Qualitative: Literature Review and Case Study	2	3	
	8	Sample Suitability	The model was developed by sampling various literature that describes Lean, VE, FMEA and Six Sigma. However, previous literature detailing the integration of these methods was not included. The proposed method was validated at a global call centre within the manufacturing industry.	2	3	
	9	Data Collection Methods	The sample collection methods were not specified.	0	3	
	10	Data Analysis Methods	Literature review/synthesis analysis methods were applied to develop the model. The literature review did not include analyses of similar studies. The Case Study data was analysed using various Lean, FMEA, TRIZ, VE, Sigma and TRIZ (the theory of inventive problem solving).	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The motivation for this study was the assertion that there exists a need to support the customer service centre and improve call-centre service quality, and this need can be met by applying an integrated tool. The purpose of the study was to develop, test and propose a VE based integrated tool to improve service quality. A literature review of the associated concepts of the various methods was conducted, however the review did not include a review of previous studies that explored the integration of these methods. The first main claim within this study was that the various improvement methods can be suitably integrated, this claim was supported by an analysis of the theoretical concepts of each method. The second main claim was that that this integrated model can effectively improve service quality, this claim was supported by Case Study evidence. Counter evidence was not explored, although the authors did highlight that competitive advantage is not only affected by quality model but is also influenced by changing market environments. The concepts were presented in a structured and logical manner. The authors recommended that future research must test the methods in other industries.	2	3	
	12	Overall Aim to minimise bias	The authors did not explicitly highlight methods that were followed to minimise bias, however the authors conducted a Case Study to test and validate their proposed model	1	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not described in a manner that facilitates auditability	0	3	50%
	14	Number of Factors Explored	VE, Lean, Six Sigma, FMEA and TRIZ data was reviewed, however there was no review of data detailing previous integration of these methods. The effectiveness and feasibility of the proposed model was explored via Case Study methodology.	2	3	
	15	Number of Studies Explored	VE, Lean, Six Sigma, FMEA and TRIZ literature was reviewed, however there was no review of literature detailing previous integration of these methods.	1	3	
	16	Data Analysis Methods	The arguments, contents analysis and case study were presented clearly in a manner that facilitates auditability.	3	3	
Lee et al (2016): Using Ict to Improve Service Quality				30	48	**63%**

Table 63: Lehman & Reiser (2004) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and the abstract contain the following themes: the achievement of a balance between value maximization and waste minimization in the construction industry through the application of Lean Construction and Value Engineering.	3	3	83%
	2	Discipline	The Construction sector, this sector is characterised by the interaction of various disciplines various (e.g. Project Management, Civil Engineering, Health and Safety Management, Risk Management)	3	3	
	3	Context	The study details the experiences of The Boldt Company, a construction company that has over 10 branches in various areas in the United States of America.	2	3	
	4	Strength of Recommendations	The recommendations contained in this study were based on a survey of Lean (and Lean Construction) literature and a brief review of VE concepts. The recommendations were also based on expert opinion and the Lean Construction experiences of The Boldt Company in the US context. This company had completed 200 LC projects in 4 years	2	3	
Validity	5	Author	T Lehman has as BSc in Construction Management and has been recognised by SAVE International as an Associate Value Specialist. P Reiser is the Corporate Vice President of The Boldt Company and has over 20 years experience in construction.	3	3	54%
	6	Literature Source	Society of American Value Engineers (SAVE) Conference, published by SAVE International	2	3	
	7	Study Design	Qualitative: Case study and Literature review	2	3	
	8	Sample Suitability	Two experts and employees of The Boldt Company provided an account of their experiences within the company. They also reviewed Lean Construction literature and briefly discuss VE literature. The Boldt Company had completed 200 LC projects in 4 years	2	3	
	9	Data Collection Methods	The literature collection methods were not specified and The Boldt Company experience data collection method was not specified	0	3	
	10	Data Analysis Methods	A literature review, explanations, arguments, expert opinion and experiences were utilised in the analysis process.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The motivation for this paper was an assertion that customer expectations can be met via a balance between value maximization and waste minimization. The purpose of the paper was to show that the integration of Lean and VE can be used (is used by The Boldt Company) to achieve the required balance between waste minimization and value maximization. The main claim found in the paper is that the integration of Lean Construction and VE results in a balance between value maximization and waste minimization; this claim was supported by a review of literature and details of The Boldt Company experience. The evidence provided details the techniques applied and general improvements made but does not contain details of numerical results within specific contexts. Data analysis was conducted using explanations, literature review, logical reasoning and industry experience. The limitations and future research implications were not discussed, however the authors highlighted key success factors.	2	3	
	12	Overall Aim to minimise bias	The authors did not explicitly highlight bias minimisation methods.	0	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not specified in a manner which facilitates auditability	0	3	25%
	14	Number of Factors Explored	The literature review focused primarily of Lean Construction, minimal VE data was reviewed. The Boldt Company data detailed techniques applied and general improvements made but did not include descriptions of specific applications.	1	3	
	15	Number of Studies Explored	The literature review focused primarily of Lean Construction, minimal VE data was reviewed.	1	3	
	16	Data Analysis Methods	The literature review data analysis methods were presented in an auditable manner, however The Boldt Company data analysis methods were not.	1	3	
Lehman & Reiser (2004): Maximizing value & minimizing waste: Value Engineering & Lean Construction				26	48	**54%**

Table 64: Mandelbaum et al. (2010) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: An examination of potential synergies between VE and Lean Six Sigma. VE is explored as a individual method, however Lean is explored within the Lean Six Sigma context.	2	3	83%
	2	Discipline	The concepts examined in this research belong to the Industrial Engineering Discipline. This concepts within this discipline are applied to various other disciplines.	3	3	
	3	Context	The study was not set in any particular environment, but it was funded by the Institute of Defense Analyses in the US.	3	3	
	4	Strength of Recommendations	The authors analyse the methodological phases of VE and Lean Six Sigma as well as the similarities and differences between the two methodologies. Their analyses were not based on any particular context. Their recommendations were proposed for products, services and processes irrespective of life-cycle. They did not specify industry context-based barriers and facilitators to synergy.	2	3	
Validity	5	Author	J Mandelbaum appears in 5 research articles on Research Gate and has published 1 book found on Google books. H W Williams appears in 1 research article on Research Gate and has published 1 book found on Google books. A.C Hermes appears in 2 research articles on Research Gate and has published 1 book found on Google books.	3	3	63%
	6	Literature Source	The paper was published by the Institute of Defense Analyses available through Google Scholar.	3	3	
	7	Study Design	Qualitative: Literature Review, Content Analysis	2	3	
	8	Sample Suitability	The authors conducted a comprehensive review of Lean Six Sigma and VE literature. They analysed literature detailing the various methodological phases, concepts, tools and techniques of the two methodologies. Additionally, the authors conducted an analysis of previous literature that proposed similar integrated methods. The literature sampled was conceptual data and minimal empirical data was used in the analysis.	2	3	
	9	Data Collection Methods	The sample collection methods were not described.	0	3	
	10	Data Analysis Methods	The authors analysed the data using a cross referencing method, explanations, arguments, logical reasoning and facts. No empirical methods were utilised to validate the proposals.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the argument that single Continuous Improvement methodologies are not suited to solve all problems, they can become obsolete if they are not integrated with new developments and integrating multiple methodologies can enhance benefits. The purpose of the research was to examine the leverage opportunities that facilitate the integration of Lean Six Sigma and VE. The first main claim was that the differences between Lean Six Sigma and VE provide integration opportunities, the authors conducted cross referencing and literature reviews to support this claim. The second main claim was that the integration of these two methodologies results in synergistic benefits, the authors did not provide empirical evidence to support this. The research was presented in a structured and logical manner. The authors concluded the research by proposing certain integration opportunities. They highlighted the limitations of their cross referencing method and outlined that integration opportunities differ depending on whether the implementation is for a product, service or construction projects. They highlighted the required conditions for integrating one method with another. The authors did not offer any empirical validation for the proposed.	2	3	
	12	Overall Aim to minimise bias	The authors did not highlight any specific methods utilised to minimise bias, however they did highlight the limitations of their analyses	1	3	
Reproducibility	13	Data Collection Methods	The literature (data) collection methods were not discussed in a manner that facilitates auditability	0	3	67%
	14	Number of Factors Explored	The authors did not explore various potential barriers or facilitators to implementing integrated approaches	2	3	
	15	Number of Studies Explored	The authors reviewed Lean Six Sigma and VE literature. They also discussed previous literature that proposed similar integration models.	3	3	
	16	Data Analysis Methods	The data analysis was conducted using facts, logical reasoning and arguments as well as a detailed cross-referencing method in a manner which facilitates auditability. The authors used real cases and hypothetical examples to illustrate application.	3	3	
Mandelbaum et al (2010): Value Engineering Synergies With Lean Six Sigma				33	48	**69%**

Table 65: Musa et al. (2016) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: the integration of Lean Construction and VE to achieve synergy in defining the value concept. The themes are focused on the value concept definition.	2	3	75%
	2	Discipline	Construction sector. This sector relies on the interaction of various disciplines (e.g. Project Management, Civil Engineering, Health and Safety Management, Risk management)	3	3	
	3	Context	The research was conducted in the Construction Industry, directed at organisations who apply Lean Construction. It was not set in a particular environment because it is a literature review.	2	3	
	4	Strength of Recommendations	The recommendations were based on a synthesis of literature. Peer-reviewed articles, conference papers and books found in various databases (e.g. Scopus, ProQuest and Google Scholar) were collected. The literature selected for review was used to conduct a comparative analysis of Lean Construction and VE based on the concept of value. The recommendations were based on a theoretical analysis and were not validated empirically.	2	3	
Validity	5	Author	M. Musa is a PhD student at Nottingham Trent University who appears in 1 publication on Research Gate. C Pasquire is a Professor at Nottingham Trent University who appears in 95 publications with 787 citations on Research Gate. A Hurst is a Senior Lecturer at Nottingham Trent University who appears in 10 publications with 21 citations on Research Gate.	3	3	75%
	6	Literature Source	IGLC 2016 - 24th Annual Conference of the International Group for Lean Construction with the full text paper made available on Research Gate	2	3	
	7	Study Design	Qualitative: Literature Review: Content Analysis	2	3	
	8	Sample Suitability	A sample of 35 peer-reviewed papers, conference papers and books were utilised to conduct the literature review. These were collected from Scopus, ProQuest and Google Scholar databases using a search strategy that covered 26 years.	2	3	
	9	Data Collection Methods	The literature was collected through the application of a search strategy that had the following characteristics: 26 years publication period; search Scopus, ProQuest and Google Scholar; the use of an inclusion/exclusion criteria, the use of Lean Construction, VE and value related search terms.	3	3	
	10	Data Analysis Methods	The data was first assessed based on context and relevance to the topic. Once selected for review, the literature was assessed using Content Analysis methods.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the assertion that there was no consistent understanding of value within Lean Construction. The purpose of the study was to investigate the value concept within Lean Construction and in order to determine opportunities where the two methods can be integrated to obtain synergistic benefits in defining the value concept. The first claim within this study was that there was inconsistent understanding of value in Lean Construction, this was supported by literature. The second claim was that Lean Construction can be suitably integrated with VE to obtain synergy in defining the value concept, this was supported by a comparative analysis using secondary data. The authors explored the value concept within Lean Construction and VE through a literature review. They made reference to previous studies that sought to achieve similar synergistic benefits of method integration. They highlighted that their study was limited by a lack of primary data, they also proposed that future research must investigate Lean Construction and VE integration empirically.	3	3	
	12	Overall Aim to minimise bias	The authors did not explicitly highlight the methods used to minimise bias. However, they followed a systematic literature review methodology in collecting and analysing data.	1	3	
Reproducibility	13	Data Collection Methods	The authors provided some details of the data collections methods, this allows auditability.	3	3	83%
	14	Number of Factors Explored	The research contained a theoretical exploration of synergistic opportunities. These were not validated using empirical factors	2	3	
	15	Number of Studies Explored	The authors reviewed 35 documents found in 3 databases using Free-text searching methods. The research paper does not show evidence of the use of exhaustive search methods that include Bibliographic, Citation and Manual searching. Therefore it cannot be said that the sufficient literature was reviewed.	2	3	
	16	Data Analysis Methods	The literature was analysed in an auditable manner.	3	3	
Musa et al (2016): Where Lean Construction and Value Management meet				37	48	**77%**

Table 66: Nassey (2004) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and the abstract contain the following themes: the application of Lean and VE to improve layout and process in a sandblasting production shop. The two methodologies were integrated to make specific improvements within a certain context.	2	3	58%
	2	Discipline	Manufacturing sector, this sector contributes 15% to the global GDP.	3	3	
	3	Context	This study was based at Intersign Corporation, a signage manufacturing company that employed less than 100 workers. The project was based in the sandblasting department of this company. This department employed 11 people.	1	3	
	4	Strength of Recommendations	The recommendations were made based on a successful application of integrated Lean and VE at a small signage manufacturing company in Chattanooga in the US. The recommendations were based on theoretical and empirical factors.	1	3	
Validity	5	Author	The author completed this study as part of MSc research at the University of Tennessee In Chattanooga.	2	3	63%
	6	Literature Source	This thesis was published by the University of Tennessee in Chattanooga.	2	3	
	7	Study Design	Qualitative: Case Study	2	3	
	8	Sample Suitability	This study was based at Intersign Corporation, a signage manufacturing company that employed less than 100 workers. The project was based in the sandblasting department of this company, this department employed 11 people. The integrated Lean and VE model was applied only to improve layout and process.	2	3	
	9	Data Collection Methods	The collection method of the reviewed literature was not specified. The company data was collected through interviews, application of the Lean layout approach: observation and evaluation and the application of the VE approach: observation, evaluation, function analysis.	2	3	
	10	Data Analysis Methods	The data was analysed using Lean (Layout) and VE principles (process-function analysis). There was no evidence provided that shows that a Lean and VE multidisciplinary team approach was used in the analysis on the data.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the organisation's need to gain competitive advantage. The purpose of the study was to evaluate the layout and process of the company's sandblasting department and provide improvement recommendations using Lean and VE principles. The main claim contained in this study is that Lean and VE techniques can be integrated to improve layout and processes within sandblasting department of a manufacturing company, this claim was supported by a literature review and by the application of both methods using a Case Study approach. This application resulted in improvements in time, costs and safety. However, the conditions that facilitated success were not highlighted, nor were the barriers to integrated method application. The author highlighted the factors that require special attention in order to achieve success. The study limitation were outlined, these were related to the conditions that existed during implementation. Implications for future research were not discussed.	2	3	
	12	Overall Aim to minimise bias	The author did not explicitly highlight the methods used to minimise bias, but the study limitations were discussed.	1	3	
Reproducibility	13	Data Collection Methods	The data collection methods were clearly outlined, however it was not in a manner that facilitated auditability	1	3	58%
	14	Number of Factors Explored	Lean and VE integration was explored for the purpose of layout and process improvement only. The barriers and facilitators of the integrated approach were not analysed.	2	3	
	15	Number of Studies Explored	The author reviewed various Lean and VE literature but did not review any literature that discussed Lean and VE integration.	1	3	
	16	Data Analysis Methods	The data analysis methods were communicated in a manner that facilitated auditability.	3	3	
Nassey (2004): Implementation of Lean method and Value Analysis in the sandblasting production shop at Intersign Corporation				29	48	**60%**

Table 67: Nayak (2006) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The themes contained in the title and abstract are as follows: the integration of Lean Manufacturing and VE to achieve synergistic benefits in the Manufacturing industry. The integration is focused on a particular industry.	2	3	67%
	2	Discipline	The study was purposed for the Manufacturing sector. A sector that contributes significantly to the global GDP	3	3	
	3	Context	The focus of the recommendations is on the North American Manufacturing Industry.	2	3	
	4	Strength of Recommendations	The recommendations were based on a review and synthesis of literature with a focus on the Manufacturing industry located in North America. The recommendations are also based on the opinions of one expert, logical reasoning, explanations and facts. There was no analysis of empirical application of an integrated Lean Manufacturing and VE method.	1	3	
Validity	5	Author	B Nayak is Vice President of Manufacturing at SAVE International. He has global experience in the manufacturing industry. He holds a Ph.D. degree in Mechanical & Manufacturing Engineering from Swinburne University of Technology in Melbourne. He has published and presented numerous chapters and technical papers.	3	3	54%
	6	Literature Source	46th Annual Conference of SAVE International 2006: Managing Projects to Maximize Value, the full text paper found on Google Scholar.	3	3	
	7	Study Design	Qualitative: Literature Review, Content Analysis	2	3	
	8	Sample Suitability	Various Lean and VE literature was reviewed and the author reviewed literature that explored the integration of Lean and VE. The literature sample reviewed contained theoretical data, no empirical data was analysed.	2	3	
	9	Data Collection Methods	The methods used to collect the data were not described.	0	3	
	10	Data Analysis Methods	Literature review and synthesis methods were applied during the analysis, these methods included an exploration of facts, explanations, logical reasoning, comparative analysis and arguments.	1	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by a need to develop a Lean and VE integrated method to address cost and competitive pressure in the Manufacturing industry. The purpose of the study was to explore Lean and VE history and theoretical concepts, conduct a comparative analysis of Lean and VE and introduce an integrated model of Lean and VE. The first claim made in this study is that Lean and VE can be suitably integrated to result in synergy, the author provided support for this using a literature review and comparative analysis. The second claim is that an integrated model of Lean and VE can be applied to address cost and competitive pressure, the author proposed models and theoretical arguments to support this but did not provide empirical evidence. Various literature was reviewed and the concepts were presented in a clear and logical structure. The author highlighted that compatible and complementary application of Lean and VE is limited by knowledge, skill and experience of the practitioners and organisation. The author did not offer recommendations for future research.	2	3	
	12	Overall Aim to minimise bias	The author did not highlight methods used to minimise bias.	0	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not applied in an auditable manner.	0	3	42%
	14	Number of Factors Explored	The author reviewed various literature and theoretical data but did not review empirical data.	2	3	
	15	Number of Studies Explored	The author reviewed various theoretical literature but did not review empirical literature.	2	3	
	16	Data Analysis Methods	Some of the data analysis methods were communicated in a manner that facilitated auditability. Some data was not referenced in a standard manner.	1	3	
Nayak (2006): Lean manufacturing and Value Management convergence of divergent tools				26	48	**54%**

Table 68: Odedairo & Bell (2010) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The themes contained in the title and abstract were the following: the integration of techniques found in value methods (Lean and VE included) to develop a model suitable for small to medium enterprises in developing countries.	2	3	67%
	2	Discipline	The study focused on value methods that belong to the Industrial Engineering Discipline. This discipline is applied in various other disciplines.	3	3	
	3	Context	The study was purposed for small to medium enterprises in developing countries.	2	3	
	4	Strength of Recommendations	The recommendations were made based on a qualitative review of various case studies and literature, it was not based on empirical application of the proposed integrated value method toolkit.	1	3	
Validity	5	Author	B Odedairo holds a PhD in Industrial and Production Engineering, he is affiliated with The Bells University of Technology in Nigeria. He appears in 13 research articles on Research Gate. D Bell is affiliated with the University of Northumbria in the United Kingdom. He has a BSc in Industrial Technology and appears in 7 research articles on Research Gate.	3	3	58%
	6	Literature Source	International Journal of Basic & Applied Sciences IJBAS; full text articles found on Google Scholar.	3	3	
	7	Study Design	Qualitative: Literature Review, Content Analysis	2	3	
	8	Sample Suitability	The research contained a review of various theoretical and case study (empirical) literature. However the literature sample was not collected using systematic methods that enable determination whether the sample was obtain using exhaustive and expansive methods.	2	3	
	9	Data Collection Methods	Literature survey methods were employed but these methods were not described.	0	3	
	10	Data Analysis Methods	Literature review and synthesis methods were employed, these included arguments, logical reasoning, expert opinion and explanation of facts. There was no quantitative review of the included empirical studies.	1	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the argument that Value methods are applied extensively in large organisations but are not applied in the same manner in small to medium enterprises (SME) and therefore there is a need to develop methods which are suitable to SME application through the integration of value method techniques. The purpose of the study was to develop a function orientated value method through the integration of various techniques to facilitate implementation in SMEs in developing counties. The first claim that was made was that SME's and developing have conditions which are different to large entities and developed countries and therefore require different improvement methods, this was supported by literature. The second claim made was that the developed value method toolkit is suitable for successful implementation in SME's in developing countries, this was supported by literature reviews but was not validated through empirical application. The author presented the research in a logical and clear structure. The author concluded by highlighting the need to test and validate the proposed toolkit, he highlighted the research limitations and advised future researchers to explore barriers to implementation.	2	3	
	12	Overall Aim to minimise bias	The author highlighted limitations and recommended that the proposed model be validated empirically.	1	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not communicated in an auditable manner	0	3	50%
	14	Number of Factors Explored	The author explored the qualitative aspects of various theoretical and empirical factors. However, it was recommended that future research must explore additional factors.	2	3	
	15	Number of Studies Explored	The author highlighted that there was inadequate research related to the study. However, there was no evidence of the use of exhaustive and expansive systematic literature search methods.	1	3	
	16	Data Analysis Methods	The data was analysed in an auditable manner.	3	3	
Odedairo & Bell (2010): Framework for introducing and implementing value methods: a novel toolkit for small and medium scale industries in developing nations				28	48	**58%**

Table 69: Ogunbiyi (2011) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The themes contained in the title and abstract are the following: the implementation of value management approaches in Lean Construction (LC).	2	3	75%
	2	Discipline	Construction sector. This sector relies on the interaction of various disciplines (e.g. Project Management, Civil Engineering, Health and Safety Management, Risk management)	3	3	
	3	Context	The research was conducted in the Construction Industry, directed at organisations who apply Lean Construction. The research introduction contains a focus on LC in the United Kingdom.	2	3	
	4	Strength of Recommendations	The recommendations made were based on a literature review that was focused on theoretical concepts of Value in VE and in LC. The recommendations were also based on a review of literature detailing UK construction industry trends.	2	3	
Validity	5	Author	O Ogunbiyi holds a PhD from the University of Central Lancashire. He appears in 10 publications with 125 citations on Google Scholar. A. Oladapo holds a PhD and is a Lecturer at the University of Central Lancashire, he appears in 17 research publications found on the university's website. J Goulding is a professor at Wolverhampton University and he appears in 115 research publication on Research Gate.	3	3	50%
	6	Literature Source	RICS Construction and Property Conference; full text found on Google Scholar.	2	3	
	7	Study Design	Qualitative: Literature Review, Content Analysis	2	3	
	8	Sample Suitability	The study sample was literature that was focused on the theoretical concepts of LC and value management, industry implementation of LC and literature describing the integration of Lean and VE.	2	3	
	9	Data Collection Methods	The data collection methods were not specified. Although it can be deduced that literature survey data collection methods were utilised.	0	3	
	10	Data Analysis Methods	Literature review and synthesis methods were applied to analyse the data. These methods were qualitative.	1	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The purpose of this study was to conduct an examination of the value maximization challenges in LC, to propose a value management approach to LC and to explore the concept of value management in LC. The first claim made is that value plays a significant role in LC, this was supported by literature. The second claim is that there are challenges experienced in LC when it come to value maximization and these challenges can be addressed through integrating LC with VE, this was supported by literature. The analyses were presented in a clear and logical structure. The limitations of the study were not discussed. The study author highlighted that the study was part of ongoing PhD research.	2	3	
	12	Overall Aim to minimise bias	Bias minimization methods were not discussed.	0	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not presented in an auditable manner.	0	3	50%
	14	Number of Factors Explored	The author proposed the integration of LC and VE but did not explore how LC and VE tools and techniques can be suitably merged in a specific model. The study focused on the qualitative aspects of LC and VE concepts but not the quantitative.	2	3	
	15	Number of Studies Explored	The study did not include detailed analysis of empirical literature.	1	3	
	16	Data Analysis Methods	The data was presented in an auditable manner	3	3	
Ogunbiyi et al (2011): Innovative Value Management: assessment of Lean construction implementation				27	48	**56%**

Table 70: Parker (2005) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contained the following themes: the integration of Lean and VE because of their complementary features.	3	3	83%
	2	Discipline	The author proposes that Lean and VE can be implemented in Production, Services and Construction industries. The study is not based in any discipline, the author discusses Lean and VE and these two concepts belong to the Industrial Engineering Discipline.	3	3	
	3	Context	The study was not set in any particular environment. However, the author used manufacturing and Construction examples to support his claims.	3	3	
	4	Strength of Recommendations	The recommendations were made based on the opinions of one expert, a brief analysis of several manufacturing cases and a literature review of Lean concepts.	1	3	
Validity	5	Author	D Parker is a Certified Value Specialist who was the President of the Lawrence D Miles Value Foundation	3	3	46%
	6	Literature Source	SAVE International Annual Conference: SAVE Value Summit 2015	2	3	
	7	Study Design	Qualitative: Literature Review and Case Study	2	3	
	8	Sample Suitability	The Literature sample consisted of MIT research and Lean thinking principles as described by Lean Enterprise institute, however VE literature was discussed briefly. The author presented 5 cases (Manufacturing, Construction and Travel sectors, Lean and VE) as examples which he used to support his claims.	1	3	
	9	Data Collection Methods	The data collection methods were not described. Although it was evident that literature survey and Case Study methods were used to collect the data.	0	3	
	10	Data Analysis Methods	The author applied literature review and synthesis methods in his analysis. The author supported his claims by including quantitative results of empirical cases.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The purpose of the study was to show that Lean and VE are complementary and can be suitably integrated to improve value maximization efforts. The main claim found in this study was that Lean and VE are complementary. The author supported this claim by analysing literature and by providing case examples. The author did not review any similar literature where Lean integrated VE has been proposed. The author briefly reviewed VE literature. The paper was presented in a logical and structured manner. the data analysis relied on expert opinion, logical reasoning, quantitative empirical case results and literature. The study limitations and implications for future research were not outlined.	1	3	
	12	Overall Aim to minimise bias	The bias minimisation methods were not outlined.	0	3	
Reproducibility	13	Data Collection Methods	The author did not outline the data collection methods. However, the literature sources were listed.	1	3	33%
	14	Number of Factors Explored	The study included an exploration of both the qualitative and quantitative effects of Lean and VE. The author explored Lean literature and briefly described VE. The study did not include a review of Lean integrated VE literature.	1	3	
	15	Number of Studies Explored	The study included a detailed review of Lean literature, however VE literature was discussed briefly. The study did not include a review of Lean integrated VE literature.	1	3	
	16	Data Analysis Methods	Some data was analysed in an auditable manner (well referenced literature). Some data was not analysed in an auditable manner (inconsistent referencing and cases studied lack some detail).	1	3	
Parker (2015): Lean As A Value Enhancing Methodology				25	48	**52%**

Table 71: Prahladaraj (2004) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and the abstract contain the following themes: the application of Lean and VE to improve the internal distribution system of a company in the manufacturing industry. The two methodologies were integrated to make specific improvements within a certain context.	2	3	67%
	2	Discipline	Manufacturing sector, this sector contributes 15% to the global GDP.	3	3	
	3	Context	This study was based at an XYZ Corporation located in Georgia USA, it is a cooking range manufacturing company that employed 1500 workers. The project was focused on the internal distribution system (for Very High Pressure adhesives) within this company.	1	3	
	4	Strength of Recommendations	The recommendations were made based on a successful application of integrated Lean tools (seven waste types) and VE tools (FAST diagram) at large manufacturing company in Georgia, USA. They were based on a review of Lean and VE literature. In summary, the recommendations were based on theoretical and empirical factors.	2	3	
Validity	5	Author	The author completed this study as part of MSc research at the University of Tennessee In Chattanooga.	2	3	63%
	6	Literature Source	This thesis was published by the University of Tennessee in Chattanooga.	2	3	
	7	Study Design	Qualitative: Case Study	2	3	
	8	Sample Suitability	This study was based at an XYZ Corporation located in Georgia USA, it is a cooking range manufacturing company that employs 1500 workers. The project was focused on the internal distribution system (for Very High Pressure adhesives) within this company. The study only show the integrated implementation of a few Lean and VE techniques.	2	3	
	9	Data Collection Methods	The collection method of the reviewed literature was not specified. The company data was collected through interviews, observations and the VE FAST diagram approach.	2	3	
	10	Data Analysis Methods	The data was analysed using Lean (seven waste types) and VE principles (FAST diagram and function analysis). The author highlighted that the VE and Lean multidisciplinary team approach was not applied, all analyses were made by one observer which may have contributed to bias.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the organisation's need to improve quality from the customer perspective as well as to address internal distribution system problems associated with time, overproduction, and inventory factors.. The purpose of the study was to develop a Lean distribution system and provide improvement recommendations using Lean and VE principles. The main claim contained in this study is that Lean and VE techniques can be integrated to identify waste within a manufacturing company, this claim was supported by a literature review and by the application of FAST diagram and Lean methods using a Case Study approach. This application resulted in the proposal of a new system that would result in increased productivity. The study limitations were outlined, these were related to the scope of the study and the fact that the functional analysis was completed by the researcher only. The author recommended future research directions.	2	3	
	12	Overall Aim to minimise bias	The author did not explicitly highlight the methods used to minimise bias, but the study limitations were discussed.	1	3	
Reproducibility	13	Data Collection Methods	The data collection methods were clearly outlined, however it was not in a manner that facilitated auditability	1	3	58%
	14	Number of Factors Explored	Lean and VE integration was explored for the purpose of waste identification and elimination only. The barriers and facilitators of the integrated approach were not analysed.	2	3	
	15	Number of Studies Explored	The author reviewed various Lean and VE literature but did not review any literature that discussed Lean and VE integration.	1	3	
	16	Data Analysis Methods	The data analysis methods were communicated in a manner that facilitated auditability.	3	3	
Prahladaraj (2004): Integration of Lean manufacturing and Value Engineering techniques to improve the internal distribution system in a manufacturing company				30	48	**63%**

Table 72: Sacadura & Tenera (2011) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: the development of a model composed of integrated VE (FAST diagram) and Lean (VSM) in the Manufacturing industry. It is not a complete integration of Lean and VE, it is an integration of specific tools.	2	3	75%
	2	Discipline	The Manufacturing sector, a sector that contributes significantly to the global GDP.	3	3	
	3	Context	The model proposed was designed for implementation within the Manufacturing sector. It was validated through application in a car parts supplier company, within a sub process with three workers.	2	3	
	4	Strength of Recommendations	The authors reviewed theoretical concepts to develop the Lean and VE integrated model. They did not review any previous literature that proposes similar Lean and VE integration models. The proposed model was validated through application in a sub process cell of a car parts suppliers, this cell had only three workers.	2	3	
Validity	5	Author	L Sacadura is affiliated with the New university of Lisbon in Portugal. A Tenera is an assistant Professor at New University of Lisbon in Portugal, she appears in 21 research publications on research Gate.	3	3	50%
	6	Literature Source	2011 International Conference on Management and Service Science; full text was found on Google Scholar	2	3	
	7	Study Design	Qualitative: Literature Review, Case Study	2	3	
	8	Sample Suitability	The authors reviewed theoretical concepts to develop the Lean and VE integrated model. They did not review any previous literature that proposes similar Lean and VE integration models. The proposed model was validated through application in a sub process cell of a car parts suppliers, this cell had only three workers.	1	3	
	9	Data Collection Methods	The data collection methods were not specified.	0	3	
	10	Data Analysis Methods	The authors applied literature review and synthesis methods to conduct a review of Lean and VE theoretical concepts for the purposes of integrated model generation. The case study features the use of Lean (VSM) and VE (Function Analysis) for data analysis.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the assertion that Lean has certain gaps; these gaps result in a lack of understanding of customer value, failure to eliminate waste in small processes and adverse impacts on innovation capability; these gaps can be addressed through integration with VE. The purpose of the study was to propose and validate a Lean and VE integrated model, one that effectively reduces Lean gaps. The research paper did not include a review of literature that proposed similar lean and VE integrated models. The main claim contained in this study is that Lean tools (VSM) can be suitably merged with VE tools (Function Analysis, FAST diagram) to minimise Lean gaps; this claim was supported using case study methodology. The authors highlighted that the limitation of the study was that it formed part of ongoing research. They also highlighted the need for further research to validate the proposed model.	2	3	
	12	Overall Aim to minimise bias	The authors did not highlight specific methods that were used to minimise bias.	0	3	
Reproducibility	13	Data Collection Methods	The literature survey data collection methods were not specified. The case study data collection methods were Lean VSM and VE's Function Analysis, however these were not outined in an auditable manner	0	3	42%
	14	Number of Factors Explored	The authors reviewed Lean and VE theoretical concepts and they tested the proposed model empirically. The authors did not address barriers and facilitators of the implementation lean integrated VE. Nor did they specify the company's existing pre-conditions that could have led to successful model implementation.	2	3	
	15	Number of Studies Explored	The authors reviewed theoretical concepts to develop the Lean and VE integrated model. They did not review any literature any previous literature that proposes similar Lean and VE integration models.	1	3	
	16	Data Analysis Methods	Some data was analysed in an auditable manner. Some of the Case study data was analysed was not analysed in an auditable manner	2	3	
Sacadura & Tenera (2011): Integrating value and Lean management in manufacturing processes				26	48	**54%**

Table 73: Salvatierra-Garrido et al. (2008) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: the integration of Lean and VE in the early stages of construction projects in low income social housing in Chile. The integration of Lean and VE is focused on the Conceptual stage of the Project Life Cycle.	2	3	83%
	2	Discipline	Construction Sector. Construction involves various disciplines (e.g. Project Management, Civil Engineering, Health and Safety Management, Risk management)	3	3	
	3	Context	The study was set in Chile social housing project aimed at housing 300 families. Although Chile is a developed country, social housing projects are relevant to the developing countries context as well.	3	3	
	4	Strength of Recommendations	The recommendations were based on a literature review of the value concepts found in Lean and VE theory. The recommended Lean and VE integrated model is based on a comparative analysis of Lean and VE theoretical value concepts. The recommendations were based on a qualitative analysis of the 300-family Chile social housing project. The authors applied Case Study data collection methods but conducted their analysis using qualitative literature review methods. The recommended Lean and VE value model was not applied.	2	3	
Validity	5	Author	J Salvatierra-Garrido hold a PhD from Loughborough University and is a Research Deputy Director at Pontifical Catholic University of Chile; he appears in 25 publications on Research Gate. C Pasquire is a Professor at Nottingham Trent University who appears in 95 publications with 787 citations on Research Gate. A Thorpe is a Dean at Loughborough University and appears in 169 publications of Research Gate	3	3	50%
	6	Literature Source	Association of Researchers in Construction Management, ARCOM 2008 - Proceedings of the 24th Annual Conference	2	3	
	7	Study Design	Qualitative: Literature review and Case Study	2	3	
	8	Sample Suitability	The authors analysed various literature detailing the theoretical concepts of value in Lean and VE. The authors applied qualitative data analysis methods to examine the a 300-family social housing project in a Chilean district. This project involved the Chilean government and 370 companies.	2	3	
	9	Data Collection Methods	The data collection methods were not specified.	0	3	
	10	Data Analysis Methods	The authors utilised literature review, arguments, facts, explanations and logical reasoning to analyse the data. The methods were qualitative and theoretical.	1	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	This study was motivated by the Chilean government social housing policy, this policy created an opportunity for the application of the Lean and VE value concepts in the early stages of construction projects. The purpose of the study was to determine whether value opportunities can be identified in the early stages of the Chilean social housing project through the application of Lean and VE. The purpose of the study was also to determine whether improvements can be achieved through the application of Lean and VE integrated value concepts. The first main claim of the study was that combined Lean and VE can result in value delivery in the early stages of social housing construction projects, this was supported by comparative analysis of Lean and VE value concepts. The second claim was that the Chilean social housing project can be improved through Lean and VE, this claim was not fully supported because it requires application of the proposed integrated model but this was not done. The authors conducted a literature review of Lean and VE theoretical concepts of value, they also reviewed literature that proposes integration of Lean and VE value concepts. The study was presented in a logical and clear manner. The researchers highlighted that the proposed integration model still required further development and testing.	2	3	
	12	Overall Aim to minimise bias	The bias minimisation methods were not outlined	0	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not specified in a manner which facilitates auditability.	0	3	42%
	14	Number of Factors Explored	The study focused on theoretical aspects, the authors did highlight that future research would focus on empirical factors.	2	3	
	15	Number of Studies Explored	The authors reviewed theoretical value concepts of Lean and VE, some Lean and VE integration literature as well as the Chilean social housing data. However, they did not exhaustively review Lean and VE integration literature, exhaustive review is integral to new model development.	1	3	
	16	Data Analysis Methods	The theoretical data was analysed in an auditable manner, i.e. references were included. However the Chilean project data was not analysed in an auditable manner.	2	3	
Salvatierra-Garrido (2008): Social housing in Chile: Opportunities to apply value concept in early stage of projects				27	48	**56%**

Table 74: Shekari & Fallahian (2007) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: the linking of VE and Lean in a sequenced manner to achieve synergistic benefits. The focus was on a particular sequence and for the purposes of synergy only.	2	3	75%
	2	Discipline	The specific discipline was not outlined. However, since Lean and VE are Continuous Improvement methodologies the study can be placed in the Industrial Engineering discipline.	3	3	
	3	Context	The study was not set in any particular environment. It was purposed for all organisations that aim to obtain competitive advantage.	3	3	
	4	Strength of Recommendations	The study was not set in any particular context. The recommendations made are based on a comparative analysis of Lean and VE theoretical concepts. This comparative analysis was based on literature. The recommendations were not based on an empirical application of the proposed model.	1	3	
Validity	5	Author	A Shekari is affiliated with the Iran University of Science and Technology.	2	3	46%
	6	Literature Source	Proceedings of the 19th International Conference on Production Research, Valparaiso	2	3	
	7	Study Design	Qualitative: Literature Review	2	3	
	8	Sample Suitability	The study sample included various Lean and VE theoretical literature. There was no review of literature that similarly proposes Lean and VE integrated models.	2	3	
	9	Data Collection Methods	The methods used to collect the data were not specified.	0	3	
	10	Data Analysis Methods	The authors utilised literature review, arguments, facts, explanations and logical reasoning to analyse the data. The methods were qualitative and theoretical. Some arguments (sequencing of Lean and VE) contained claims that were not adequately supported.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the need to develop methods which assist companies in effectively eliminating non-value adding activities in a manner which provides competitive advantage. The authors proposed that a Lean and VE integrated method would best meet this need. The purpose of the study was to develop an integrated Lean and VE model that would improve product functions, increase customer satisfaction and eliminate waste. The study claims were supported by literature. One of the claims (appropriate sequencing of Lean and VE) was not adequately supported. The study concepts were presented in a clear and logical manner. The limitations and implications for future research were not outlined.	1	3	
	12	Overall Aim to minimise bias	The bias minimization methods were not outlined	0	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not outlined in an auditable manner.	0	3	42%
	14	Number of Factors Explored	The authors reviewed Lean and VE literature. They do not review literature that proposes similar Lean and VE integration models	2	3	
	15	Number of Studies Explored	The authors reviewed Lean and VE literature. They did not review literature that proposes similar Lean and VE integration models	1	3	
	16	Data Analysis Methods	All reviewed literature was referenced. However some claims (sequencing requitements) were not supported by evidence therefore limiting auditability.	2	3	
Shekari & Fallahian (2007): A new approach to linking Value Engineering & Lean methodology				25	48	**52%**

Table 75: Thorsen (2005) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: the application of Lean's Value Stream Mapping to Value Methodology (Value Engineering), in the General Motors context. The focus was on one aspect of Lean (the VSM approach) and the perspective was limited to the General Motors context.	2	3	83%
	2	Discipline	The study was based on the General Motors experience, General Motors belongs to the Manufacturing sector.	3	3	
	3	Context	The study was conducted at General Motor, a global Manufacturing company. It was focused on their Lean system which is a Global manufacturing system.	3	3	
	4	Strength of Recommendations	The recommendations were based on the experiences of General motors (a company that had been applying Lean for 10 years), a comparative analysis of Lean VSM literature and the VE Job Plan. The analysis were based on expert opinion, logical reasoning and facts. The proposed VSM integration with VE was not tested empirically.	2	3	
Validity	5	Author	W Thorsen is an Associate Value Specialist and holds a Bachelors degree in Industrial Engineering. He has 35 years experience and is Project Planner in the Worldwide facilities Group of General Motors.	3	3	46%
	6	Literature Source	SAVE International Annual Conference	2	3	
	7	Study Design	Qualitative: Case Study	2	3	
	8	Sample Suitability	The sample analysed was the Lean initiatives at General Motors. A company that has a Global Lean Manufacturing system and has been implementing Lean for 10 years. The author also analysed Lean history literature, VSM literature and VE Job Plan literature.	2	3	
	9	Data Collection Methods	The author did not specify the methods used to collect the sample.	0	3	
	10	Data Analysis Methods	The author applied literature review analysis methods: logical reasoning, facts, arguments and expert opinion.	1	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The purpose of the paper was to demonstrate VSM techniques and their application to the Value Engineering. The main claim contained in this study was that the Lean VSM technique is similar to the VE Job plan and this similarity facilitates integration. The author supported this by describing VSM techniques and comparing them to VE Job plan techniques as part of a literature review. The ideas were presented in a structured and logical manner. The author mainly focused on VSM literature and briefly discussed VE literature. The author did not include a review of similar literature which discusses Lean and VE integration. The study limitations and implications for future research were not highlighted.	1	3	
	12	Overall Aim to minimise bias	The bias minimisation methods were not discussed	0	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not described in a manner which facilitated auditability.	0	3	25%
	14	Number of Factors Explored	The focused on the similarities between Lean's VSM and the VE Job plan but did not address the differences. The author did not discuss potential integration barriers.	1	3	
	15	Number of Studies Explored	The author mainly focused on VSM literature and briefly discussed VE literature. The author did not include a review of similar literature which discusses Lean and VE integration.	1	3	
	16	Data Analysis Methods	Some analysis was presented in an auditable manner (arguments, referenced literature). Some analysis was not conducted in an auditable manner.	1	3	
Thorsen (2005): Value Stream Mapping and VM				24	48	**50%**

Table 76: Watson (2005) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: improving the Value Engineering framework through integration with other methods (e.g. Lean). This is an integration of both methods in their entirety.	3	3	83%
	2	Discipline	The methods investigated belong to the Industrial Engineering Discipline; Industrial Engineering principles are applied in various fields.	3	3	
	3	Context	The study is a conceptual paper that is not set in any particular environment. The study was written by a member of the International Academy for Quality and presented at the ASQ Quality conference, therefore it is influenced by quality management perspectives.	2	3	
	4	Strength of Recommendations	The recommendations are based on literature review, case study and expert opinion.	2	3	
Validity	5	Author	G Watson is an Industrial Engineer who was a member of the International Academy for Quality, he has written 6 books.	3	3	46%
	6	Literature Source	ASQ World Conference on Quality and Improvement Proceedings; full text obtained on ProQuest.	2	3	
	7	Study Design	Qualitative: Literature Review, Case Study	2	3	
	8	Sample Suitability	The study sample included literature on Lean and VE (and other CI methods), and a case study that was taken from a news broadcast. Previous literature that proposes Lean and VE integration was not included.	1	3	
	9	Data Collection Methods	The methods were not specified.	0	3	
	10	Data Analysis Methods	The data was analysed using literature review methods, arguments, explanations, case study examples, expert opinion and facts.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by the claim that the intellectual framework of VE had not evolved at an expected rate from World War II until 2005. The purpose of the study was to improve the VE approach in a manner which aligns it with the developments of the three decades that preceded the year 2005. The author supported his claims with literature and a case study examples (the details of the case study context were not specified, this case was taken from a news broadcast). The ideas were presented in a structured manner. The data was analysed using expert opinion, facts, logical reasoning and arguments. The limitations and implications for future research were not specified.	1	3	
	12	Overall Aim to minimise bias	These were not specified	0	3	
Reproducibility	13	Data Collection Methods	The data collection methods were not specified in a manner that facilitates auditability.	0	3	25%
	14	Number of Factors Explored	The author did not highlight the factors which facilitate or impede the integration VE with other methods.	1	3	
	15	Number of Studies Explored	The study sample included literature on Lean and VE (and other CI methods), and a case study that was taken from a news broadcast. Previous literature that proposes Lean and VE integration was not included.	1	3	
	16	Data Analysis Methods	Some data analysis methods were communicated in an auditable manner. Some data analysis methods were not communicated in an auditable manner e.g. the case study	1	3	
Watson (2005): Putting value back into engineering				24	48	**50%**

Table 77: Wixson (2005) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: The use of VE's FAST Modelling tools and other analytical techniques to solve continuous improvement problems within a Quality Assurance Operations. The focus was on a small number of CI tools within the quality management function.	2	3	75%
	2	Discipline	The study was based in two sectors: The Energy sector and the Public Sector. The investigation involved various disciplines such as Engineering, Quality Assurance and Construction.	3	3	
	3	Context	The study was based at the Departments of Energy (Office of Price-Anderson Enforcement) within the Quality Assurance program. Energy departments form part of most government ministries and Quality Assurance is applied in various organisations within the public and private sector. However, the study focused on one office in a department which has over 20 offices.	2	3	
	4	Strength of Recommendations	The recommendations were based on a sample of 519 reports which were collected over a 1 year period. The recommendations were based on quantitative and qualitative analyses conducted by an experienced multidisciplinary team using the FAST and FMEA techniques. Minimal literature was reviewed.	2	3	
Validity	5	Author	J Wixson has 30 years experience and holds Bachelors degree in Industrial Engineering as well as an MBA from the University of Phoenix. He is a Certified Value Specialist.	3	3	63%
	6	Literature Source	SAVE International Annual Conference	2	3	
	7	Study Design	Qualitative: Case Study	2	3	
	8	Sample Suitability	The author analysed minimal FAST VE literature as well as Lean's FMEA literature. The sample used in the analysis was 519 Deficiency Reports collected over 1 year (2001).	2	3	
	9	Data Collection Methods	The sample was collected from a company database, the search coverage dates were restricted to 1 year (2001). Company information can also exist as tacit knowledge, however the data collection methods did not include methods such as interviews and Lean's Gemba for verification.	2	3	
	10	Data Analysis Methods	The author analysed FAST and FMEA literature using logical reasoning and facts. The author analysed collected data using a multi disciplinary team approach Functional Analysis, FMEA, FAST diagram, Root Cause Analysis and quantitative statistical analysis techniques such as the Pareto principle. The author did not analyse an adequate amount of literature.	2	3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The study was motivated by inadequate continuous improvement effort within the Quality Assurance Program at the USA Department of Energy. The purpose of the study was to apply VE's Functional Analysis (FAST diagram) and Lean's Root Cause Analysis and FMEA to identify areas for improvement and to propose solutions. The main claim contained within this study was that the FAST diagram and FMEA can be suitably integrated and applied to improve quality performance. The author supported this claim by first analysing the similarities and differences between FAST and FMEA, this was followed by an application of the proposed integrated model. The assertions made within this study were supported by empirical study. The data was analysed using Lean and VE methods as well as statistical analysis. The author did not analyse literature that contains similar Lean and VE integrated model proposals. The limitation and implications for future research were not discussed.	2	3	
	12	Overall Aim to minimise bias	The author did not explicitly highlight the methods used to minimise bias.	0	3	
Reproducibility	13	Data Collection Methods	The author provided the procedures (1 year period) and systems (company database) used to collect the data.	2	3	42%
	14	Number of Factors Explored	The author reviewed the FAST and FMEA characteristics that make them suitable for integration but did not highlight any potential integration barriers. The author did not discuss the context-specific conditions that facilitated the successful integration and implementation. The author did not review sufficient Lean and VE literature.	1	3	
	15	Number of Studies Explored	The author briefly reviewed literature related to the characteristics of FAST and FMEA. There was no examination of similar literature that contained similar Lean and VE integrated models.	1	3	
	16	Data Analysis Methods	The literature was not referenced in a manner which facilitated auditability. The statistical and functional analysis were presented in an auditable manner.	1	3	
Wixson (2005): A Value Management Approach to Improving Quality Performance				29	48	**60%**

Table 78: Wohnhas (2014) Critical Appraisal Analysis

Factor Group	Factor Number	Factor Name	Analysis	Rating: Weight Factor (0-None, 1-Low, 2-Medium & 3-High)	Highest Factor Score Possible	Group Factor Score
Applicability	1	Topic	The title and abstract contain the following themes: the application of VE's Function Analysis and Lean development process in the project definition stage. The integrated Lean and VE model is applied to only one stage of the project life cycle	2	3	83%
	2	Discipline	The Manufacturing sector, a sector that contributes significantly to the global GDP.	3	3	
	3	Context	The study was based at Whirlpool Corporation. This global company operates 65 factories and engineering centres. It is one of the leading appliance manufacturing globally.	3	3	
	4	Strength of Recommendations	The recommendations were based on case study data collection methods. They were based on the experiences of a global manufacturing company that is present in 130 countries. The analyses were based on expert opinion, literature review and empirical factors. The recommendations were focused on the Project definition stage only. The recommendation were based on the Whirlpool Corporation experiences and were communicated by an employee of Whirlpool, this can introduce certain biases.	2	3	
Validity	5	Author	S Wohnhas was the Regional Design for Value Manager (Europe, Middle East and Africa) at Whirlpool. He holds an MSc in Mechanical Engineering and is a Certified Value Specialist.	3	3	50%
	6	Literature Source	SAVE International Annual Conference: SAVE Value Summit 2014	2	3	
	7	Study Design	Qualitative: Case Study	2	3	
	8	Sample Suitability	The sample was a global company (Whirlpool) Corporation which employed 68 000 people and was present in 130 countries. The analysis focused on one stage of the Project Life cycle, the Project Definition Stage.	3	3	
	9	Data Collection Methods	The data collection methods were not specified, although it was evident that the Case Study data collection methodology was applied.	1	3	
	10	Data Analysis Methods			3	
	11	Hirscheim (2008) Conceptual Paper Criteria Compliance	The purpose of this study was to describe and share the Whirlpool Corporation experiences in the implementation of Value Management in Lean Product Development with Project definition. The main claim found in this study was that the use of VE tools in Lean Product Development can result in enhanced benefits. The author supported this claim by providing descriptive analyses of the Whirlpool experiences, reviewing methods and procedures and highlighting improved outcomes. Minimal literature was reviewed. The paper followed a clear and logical structure. The limitations and implications for future research were not discussed. The potential biases were not addressed.	1	3	
	12	Overall Aim to minimise bias	The methods used to minimise bias were not addressed.	0	3	
Reproducibility	13	Data Collection Methods	It was evident that the Case Study data collection methodology was applied. However, the data collection methods used were not described in a manner which facilitates auditability.	0	3	25%
	14	Number of Factors Explored	The author described (at length) the methods used to apply VE and briefly described how Lean implementation worked. He did not provide a comprehensive description for the way Lean was used to drive efficiency in knowledge and resources management.	1	3	
	15	Number of Studies Explored	The author briefly described the literature that was relevant to the analysis. He did not conduct a comprehensive literature analysis. He did not review related literature that explores similar applications.	1	3	
	16	Data Analysis Methods	The author presented the arguments in a manner that is auditable. However, no literature references were included.	1	3	
Wohnhas (2014): Value Management in Lean Product Development				25	48	**52%**

Appendix 3: Data Extraction: Lean and VE Theory & Practices

Table 79: Data Extraction: Lean and VE Theory & Practices (Development Research)

Author and Sector	Lean Theory	Lean Practices	VE Theory	VE Practices
(Ho et al., 2000)	Customer focus	PDCA Flow Analysis Pareto Analysis Continuous Improvement Teamwork Process Analysis Fishbone TQM	VE definition VE objective	5 Phase VE Job Plan
(Cell & Arratia, 2003)	Lean Thinking Lean History Value Stream TPS Waste 5 Lean Principles Required Implementation Conditions: • High volume process • Long term implementation • Large human/financial investment 7 Waste Types	Value Stream Mapping Kaizen Continuous Improvement	VE definition	6 Phases of VE Job Plan Function Analysis
(Thorsen, 2005)	Toyota Production System Value Stream Definition Value-Adding Activities Non-Value Adding Activities Waste	Value Stream Mapping Root Cause Analysis Flow Analysis	Function Function Analysis	7 Phase VE Job Plan Function Analysis
(Watson, 2005)	Toyota Production System Lean Thinking	5 Whys TQM	VE History VE definition	Function Analysis

			Value Definition Function Definition 2 Types of Functions Value Index 3 Types of Value	
(Nayak, 2006)	Lean History 7 Waste Types Lean Thinking Toyota Production System Value Stream Non-Value Add Activities Lean Manufacturing	Value Stream Mapping Kaizen Cross-functional teams Lean Process Flow Root Cause Analysis Process Flow Chart	VE History Value Definition 4 Types of Value	10 Product Evaluation Principles 7 Standard Value Analysis Questions Function Analysis Function Analysis System Technique Value Analysis Job Plan
(Shekari & Fallahian, 2007)	Lean Thinking Lean Manufacturing Waste Non-Value Adding Activities 8 Types of Waste 5 Lean Principles	Kaizen Pull System Cellular Manufacturing Continuous Improvement Teamwork PDCA Gemba Poka Yoke Visual Tools Benchmarking TQM QCC SPC 5S VSM	VE Definition VE Philosophy 2 Types of Functions	5 Value Analysis Questions Function Analysis
(J. Salvatierra-Garrido et al., 2008)	Lean Thinking Value Definition Non-Value Add Activities Lean Principles Lean Production		Value Definition VE Definition	Function Analysis
(Mandelbaum et al., 2010)	Lean History Lean Thinking	Brainstorming 5 Whys	VE History Team Composition Criteria	Function Analysis

	Value Creation 7 Types of Waste Waste Lean Six Sigma Value Stream Variation (Mura)	Fishbone Diagram Pareto Analysis Failure Modes and Effects Analysis Flow Analysis JIT Pull System 5 S Continuous Improvement Visual Control Mistake Proofing Standardization Process Balancing	Function Definition 4 Types of Functions Function Worth	Function Analysis System Technique Pareto Analysis Creativity Techniques 8 Phase VE Job Plan
(Odedairo & Bell, 2010)	JIT Manufacturing Lean Manufacturing Waste	JIT 5S Kaizen VSM SMED Teamwork VSM TQM	Value Engineering Definition Customer Orientated Value Engineering Environmental Value Engineering	5 Phase Job Plan Value Analysis Cross-Functional Team Environmental Value Index Target Costing
(Kheradia, 2011)	Lean History Lean Six Sigma Toyota Production System 8 Types of Waste Mura Muri Value Creation	TQM FMEA JIT Kaizen Change Management VSM Autonomation Poka Yoke Layout Standardization Total Productive Maintenance Quick Changeover	VE Philosophy VE Definition Value Definition	Function Analysis System Technique Function Analysis 8 Phase VE Job Plan

		Quick Changeover Cellular Manufacturing Kanban Pull System Teamwork Visual Control Continuous Improvement 5S		
(Ogunbiyi et al., 2011)	Lean Construction Waste Elimination Lean Thinking Value Definition Value-Adding Activities Non-Value-Adding Activities	Supply Chain Management Poka Yoke VSM Last Planner System 5 Whys Flow Analysis Continuous Improvement JIT Production	Value Management Philosophy Value Concept 3 Types of Value	Function Analysis Function Analysis System Technique Objectives Hierarchy Criteria Weighting Technique Issues Generation and Analysis 5W's and H SWOT Analysis Risk Analysis Value Analysis Matrix
(De Hemmer, 2012)	Lean Manufacturing	FMEA Target Costing VSM	VE Origin Value Definition Function (or Utility) Definition Cost Definition	
(Parker, 2015)	5 Lean Principles Value Definition Lean Thinking 7 types of waste Toyota Production System	Value Stream Mapping JIT-Delivery Single Piece Flow Level Scheduling Flow Analysis Pull System Single Minute Exchange of Dies Cell Manufacturing Takt time	Function Analysis	Function Analysis Function Analysis System Technique The Value Job Plan

(Musa et al., 2016)	Lean Construction Value Definition Value-adding activities Non-Value adding activities Flow Concept Lean Thinking		Value Definition Function Concept	
(Ekanayake & Sandanayake, 2017)	Waste The 5 Lean Principles Lean Construction Lean Thinking Non-Value Add Activities	Continuous Improvement	Function definition VE definition	3 Phase VE Job Plan (6 subphases) Function Analysis

Table 80: Data Extraction: Lean and VE Theory & Practices (Application Research)

Author and Sector	**Lean Theory**	**Lean Practices**	**VE Theory**	**VE Practices**
(Chakravartty, 1991)	JIT Origin TPS 7 Types of Waste	JIT-Manufacturing TQM Pull System Housekeeping Balanced Flow Visual Control Preventative Maintenance Cellular Manufacturing Lean Layout Streamlining Levelling Setup Reduction Zero Defect TQM	VE Origin VE definition Value Definition 4 Types of Value	6 Phases VE Job Plan
(Lehman & Reiser, 2004)	Lean Construction (LC) LC short term goals Lean History LC History LC Goals	Cross-Functional teams Standardization Kanban 5S Target Costing	Value Maximisation	Value Engineering Methodology

	LC Strategy	Pull Scheduling Kaizen Total Quality Control Statistical Quality Control JIT Supply Chain Last Planner System		
(Nassey, 2004)	Lean History 7 Waste Types Lean Definition Non-Value Add in Layout Lean Layout Principle Lean Manufacturing Lean Thinking TPS Flow Concept Mura	Lean Layout Flow Analysis Gemba Activity Relationship Diagram Process Chart Pull System	VE History Value Definition VE Definition VE Objectives Function Definition	6 Phase Job Plan Pareto Analysis Functional Process Analysis Function Analysis System Technique Value Index
(Prahladaraj, 2004)	Lean History 7 Types of Waste Mass production Lean Manufacturing Value Add Activities Non-Value Add Activities Toyota Production System 5 Phases of Lean Implementation	Kanban Value Stream Mapping 5S Visual Management Tools Total Productive Maintenance Single Minute Exchange of Dies Mistake Proofing Standardized Work Kaizen Cell Production Lean Layout Flow Analysis Heijunka	VE definition 3 Types of Value Value Definition Worth definition Value Index Function Definition 4 Types of Functions	5 Phase Job Plan Function Analysis Function Analysis System Technique
(Wixson, 2005)		FMEA RCA Continuous Improvement Total Quality Management	Basic Function Definition Function Analysis	Function Analysis FAST Diagram The VE Job Plan

(Borgianni et al., 2010)	Lean Manufacturing Conditions Required Lean Implementation • Under Capacity • Scheduling and Innovation requirements for products • and processes Waste Non-Value Add Activities	Gemba Pull System JIT Supply Chain JIT Manufacturing	Value Definition	Value Analysis
(Sacadura & Tenera, 2011)	Waste Elimination 7 Types of Waste Non-Value Adding Activities Muda I: Wasteful but Necessary Activities Muda II: Pure Waste Activities to be eliminated immediately 5 Lean Principles Value Definition Lean Management	VSM Flow Analysis	Value Definition Function Definition User Related Functions Product-Related Functions	Function Analysis Function Analysis System Technique 5 Phase Job Plan
(Wohnhas, 2014)	Value Streams Value Creation Flow Lean Processes Lean Product Development	Standardization Failure Mode Effect Analysis	Function Analysis Function Definition	Function Analysis Function Analysis System Technique Cost Function Worksheet
(Lee et al., 2016)	Lean Management Value Concept TPS Lean Origin Non value add activities Value add activities	FMEA VSM Pull System	Function Definition	6 Phase Job Plan Function Analysis Value Index

Table 81: Lean theory and practices utilised to form hybrid models

Reference	Lean Theory and Practices													
Chakravartty (1991)	JIT Manufacturing													
Ho et al. (2000)	TQM: QFD	TQM: Design for Manufacturability												
Cell & Arratia (2003)	Lean Methodology	7 waste types	Kaizen	VSM	Waste Elimination	Lean Culture								
Lehman & Reiser (2004)	Lean Construction													
Nassey (2004)	Lean Layout	Flow Concept	Process Chart	Relationship Diagram	Waste Elimination									
Prahladaraj (2004)	7 Waste Types	Flow Chart	Non Value Add Activities		Waste Elimination									
Thorsen (2005)	VSM													
Wixson (2005)	FMEA	RCA												
Watson (2005)	5 whys	Lean Management	Waste Elimination	Right First Time										
Nayak (2006)	CI	VSM												
Shekari & Fallahian (2007)	Lean Planning	Value Definition	VSM	CI	NVA	Pull System	Muda	Waste Elimination	Brainstorming					
Salvatierra-Garrido et al. (2008)	Lean Thinking													
Borgianni et al. (2010)	Gemba	Lean Thinking												
Mandelbaum et al. (2010)	Lean Six Sigma	5 whys	Fishbone Diagram	FMEA	Waste Elimination	5S	JIT	Pull System	Lean Manufacturing	Lean Process				
Odedairo & Bell (2010)	VSM	TQM: QFD	NVA											
Kheradia (2011)	Lean Six Sigma	Flow Analysis	Process Analysis											
Ogunbiyi et al. (2011)	Lean Construction													
Sacadura & Tenera (2011)	Muda I: Wasteful but Necessary	Muda II: Pure Waste	VSM	Waste Elimination										
De Hemmer (2012)	Lean Manufacturing	Lean Process												
Wohnhas (2014)	Lean Culture	Lean Management	Lean Knowledge Management	Standardization	FMEA									
Parker (2015)	Lean Manufacturing	Cell Manufacturing	Takt Time	Flow Analysis	Lean Culture	5 Lean Principles	VSM	7 waste types	Visual Mangament	Pull System	JIT	SMED	Single Piece Flow	Waste Elimination
Lee et al. (2016)	FMEA	Lean Thinking	VSM											
Musa et al. (2016)	Lean Construction													
Ekanayake & Sandanayake (2017)	5 Lean Principles	Value Definition	Pull System	Flow Analysis	Non Value Add Activities	Waste Elimination	Team Composition	CI	VSM					

Table 82: VE theory and practices utilised to form hybrid models

Reference	VE Theory and Practices				
Chakravartty (1991)	VE Job Plan	Function Analysis	FAST Diagram		
Ho et al. (2000)	Function Analysis				
Cell & Arratia (2003)	VE Job Plan	Function Analysis	VE Creativity Techniques	VE Methodology	
Lehman & Reiser (2004)	VE Methodology				
Nassey (2004)	VE Job Plan	Function Definition	Function Analysis	FAST Diagram	Function Worth
Prahladaraj (2004)	FAST Diagram	Function Analysis			
Thorsen (2005)	VE Job Plan				
Wixson (2005)	VE Job Plan	Function Analysis	FAST Diagram		
Watson (2005)	Function Analysis				
Nayak (2006)	VE Job Plan				
Shekari & Fallahian (2007)	Brainstorming	Function Analysis	VE Prioritization		
Salvatierra-Garrido et al. (2008)	VE Job Plan	VE stakeholder Engagement			
Borgianni et al. (2010)	VE Job Plan	Function Analysis			
Mandelbaum et al. (2010)	Function Analysis	VE Creativity Techniques	Cost/Function Analysis	VE Methodology	VE Stakeholder Engagement
Odedairo & Bell (2010)	Function Analysis	Pareto	Job Plan		
Kheradia (2011)	Cost/Function Analysis	Function Analysis			
Ogunbiyi et al. (2011)	VE Project Briefing	VE Project Development			
Sacadura & Tenera (2011)	Function Analysis	FAST Diagram			
De Hemmer (2012)	VE Job Plan				
Wohnhas (2014)	Function Analysis	Benchmarking			
Parker (2015)	FAST Diagram	Function Analysis	VE Job Plan		
Lee et al. (2016)	VE Job Plan	Function Analysis			
Musa et al. (2016)	Value Definition	Value Delivery			
Ekanayake & Sandanayake (2017)	VE Job Plan	Functional Analysis	Team Composition		