Development of a Framework for a Lean Based Water and Energy Efficiency Tool

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Abstract

The manufacturing industry of South Africa is the sector consuming the largest portion of the total energy consumption and second largest portion of total water consumption per annum nationally. With a significant increase in electrical energy cost in recent years, together with the reserve energy margin dropping below the minimum level required for sustainable operation of energy utilities, energy efficiency improvement is becoming imperative for organisational success as well as national economical sustainability. This paper explores selected Lean manufacturing principles and its positive effect on energy and water efficiency. Although the implementation of Lean manufacturing techniques naturally leads to the improvement of energy and water intensity, the author believes that there is even greater potential in the development of a Lean based tool which will specifically focus on the improvement of energy and water efficiency. For this purpose the value stream mapping tool was chosen as the foundation. This paper continues to explain the process undergone to develop standardised energy and water specific waste categories to be used in conjunction with the traditional Lean wastes. The study concludes by detailing the development of the tool, together with its framework for implementation.

Keywords: Energy efficiency, lean manufacturing, value stream mapping, waste, water efficiency.

Introduction

The South African manufacturing industry is facing an increasingly challenging task to remain profitable, as a consequence of the increase in energy and water prices in recent years. The cost of energy has increased by 467% between 2000 and 2012 (Eskom, 2012). Figure 1 shows the electricity tariff increase of each year, from 2000 to 2014, in comparison to the year before (Eskom, 2014).

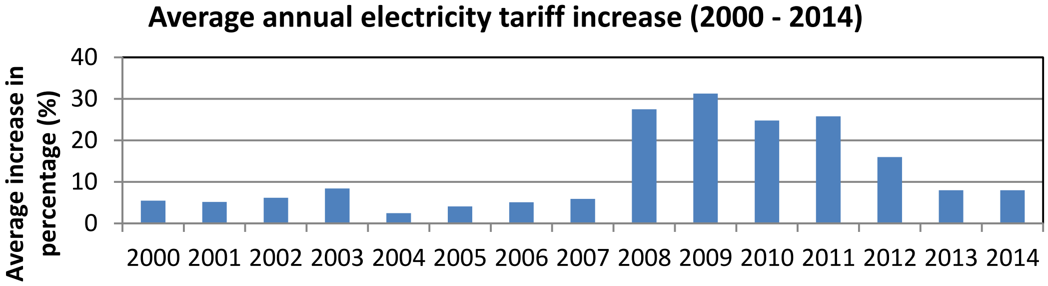

Figure 1. Eskom's (South Africa's main energy utility) average annual electricity tariff increases from 2000 to 2014 plotted in percentage (Eskom, 2014)

An increase of the average electricity tariff of 139%, between from 2008 to 2012, in comparison to 19%, of the 5 years prior to 2008, has given birth to a renewed urgency for

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South African companies to become more energy efficient, especially since tariff increases have been higher than annual national inflation levels since 2003 (Ramokgopa & Pietersen, 2007). In order for South African manufacturers to remain competitive in the world market, they have to reduce their operating costs which substantially increased after 2008 (as a result of significant price increases from 2008 to 2012 as illustrated in Figure 1). This has forced manufacturers to reduce their energy consumption and increase their process energy efficiency.

Figures 2a and 2b shows that South African industry is the largest consumer of energy (36.2% of total consumption in 2004) (DOME, 2009) and the second largest consumer of water (27% of total consumption in 2004) (DWAF, 2004) of all sectors in the country.

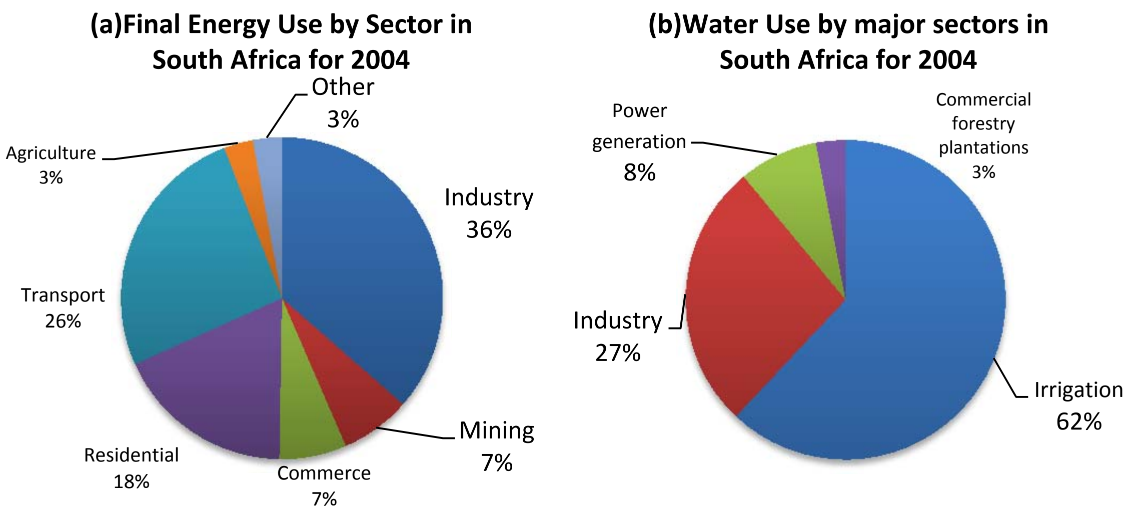

Figure 2.(a) The breakdown of the final energy use by sector (DOME, 2009) and (b) the water use by major sectors in South Africa for 2004 (DWAF,2004)

A minimum electricity reserve margin of 15% is required to allow for regular maintenance of power plants and to ensure that power plants are not overloaded (Wilson and Adams, 2006). The electricity reserve margin has dropped from 25% in 2002 to below the minimum 15% level in 2011 (Ndlovu, 2012). To restore the reserve margin, the electricity generation capacity from the supply side needs to be increased or the electricity demand from the demand side needs to be decreased.

Demand side management initiatives in South Africa currently include load shifting, load scheduling, energy efficiency and strategic growth in order to yield a positive reduction in energy demand (Grobler, den Heijer & Steyn, 2008). This paper focuses on the development of a tool to improve the water and energy efficiency on the demand side. Traditional energy efficiency interventions have been conducted on an ad-hoc basis to achieve large energy savings in the short term, however, the author believes that a continuous improvement approach to water and energy efficiency interventions will yield larger improvements in the long term.

The following section provides a concise literature review of the history and the key principles of Lean manufacturing.

Lean Manufacturing

Lean production is a term that was coined by Womack, Jones and Roos (1990) in their book *The Machine that Changed the World*, which was a study conducted for Massachusetts Institute of Technology (MIT) on the Toyota Production System (TPS). Nicholas (2011) defines Lean production as "management that focuses the organization on continuously identifying and removing sources of waste so that processes are continuously improved".

Taiichi Ohno (1912 - 1990) identified seven wastes which exist in any manufacturing environment (Stevenson, 2009), namely excess inventory, overproduction, waiting time, unnecessary transport, processing waste, inefficient work methods and product defects. These wastes are all aspects of production which are non-value adding and that the end customer is not willing to pay for.

Lean tools and techniques were developed over the years to eliminate or reduce waste in manufacturing processes. These techniques and tools are characterized under five Lean principles, as illustrated in Figure 3.

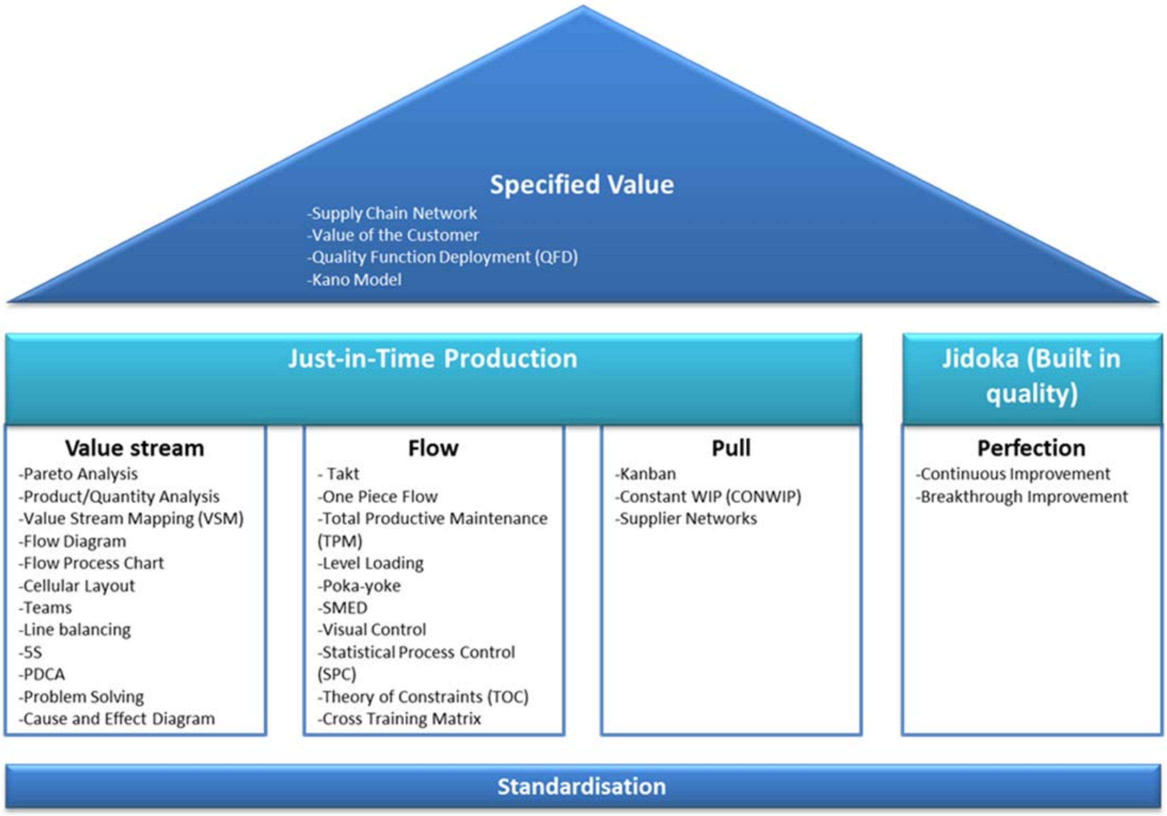

Figure 3. Illustration of the five Lean principles with its respective tools and techniques listed underneath each pillar [Constructed from Womack and Jones (2003:15-26) and Bicheno & Holweg (2009:17)]

The five lean principles listed in a logical order of implementation are; specifying the value, identifying the value stream, establishing flow, letting the customer pull production and striving for perfection (Womack and Jones, 2003).

One of the most prominent philosophies in Lean is *kaizen*, a Japanese term for continuous improvement. *Kaizen* focuses on sustainable small incremental improvements in a process, which eventually adds up to larger improvements. The author believes that a similar approach can be followed to reduce energy and water waste in manufacturing processes.

It has been observed that the implementation of Lean manufacturing techniques naturally leads to energy efficiency improvements (Seryak, Epstein and D'Antonio, 2006). The energy benefits are summarised in Table 1.

Table 1. Energy efficiency opportunities arising from implementation of Lean manufacturing techniques

Lean Manufacturing Technique	Energy Efficiency Opportunity
Inventory reduction	Reduced space required, resulting in less energy required for lighting, space heating / cooling and ventilation.
Changeover time reduction	Production equipment idling during changeovers, therefore less idle time with changeover time reduction.
Downtime reduction	Decreased idle time for production depended equipment.
Setup time reduction	Quicker setup times result in increased production time, therefore energy usage per unit decreases.
Cycle time reduction	Energy use of operating hour depended equipment remains the same for increased output, decreased idle time for production depended equipment and decreasing cycle times may increase equipment operating efficiency.
Increased throughput	Production equipment depended on operating hours. Decreased energy intensity.
Rework / Scrap Reduction	Energy usage of rework a waste. Energy use per quality product will decrease with reduction in scrap and reworks.
Part travel reduction	Decrease in WIP, thus shorter travel times resulting in decreases usage of energized equipment (conveyor belts, monorails, and vacuum tubes).
Space reduction	Decreased use of lighting and ventilation due to reduced open floor space.

From research results shown in Table 1 it would be reasonable to assume that greater savings could be realized if a Lean technique is utilized which specifically focusses on energy and water waste in a process.

In order for a Lean tool to be specifically used for energy and water efficiency improvement, specific energy and water waste categories need to be established to supplement the seven basic Lean wastes. The next section focusses on the determination of these additional energy and water wastes. It also provides an overview of the methodology which was formed to establish these waste categories.

Energy

Energy used in the various sectors is generated by the conversion of primary energy sources (coal, crude oil, nuclear, hydro, gas, renewable) into secondary energy sources (electricity, biomass, petroleum, liquefied petroleum gas). Secondary energy sources are referred to as energy carriers.

The decision making process followed to create the standardised energy and water waste categories is shown in Figure 4. Only causes of energy waste were considered for the purposes of this exercise, with the assumption that the root causes of water waste will be similar to that of energy wastes.

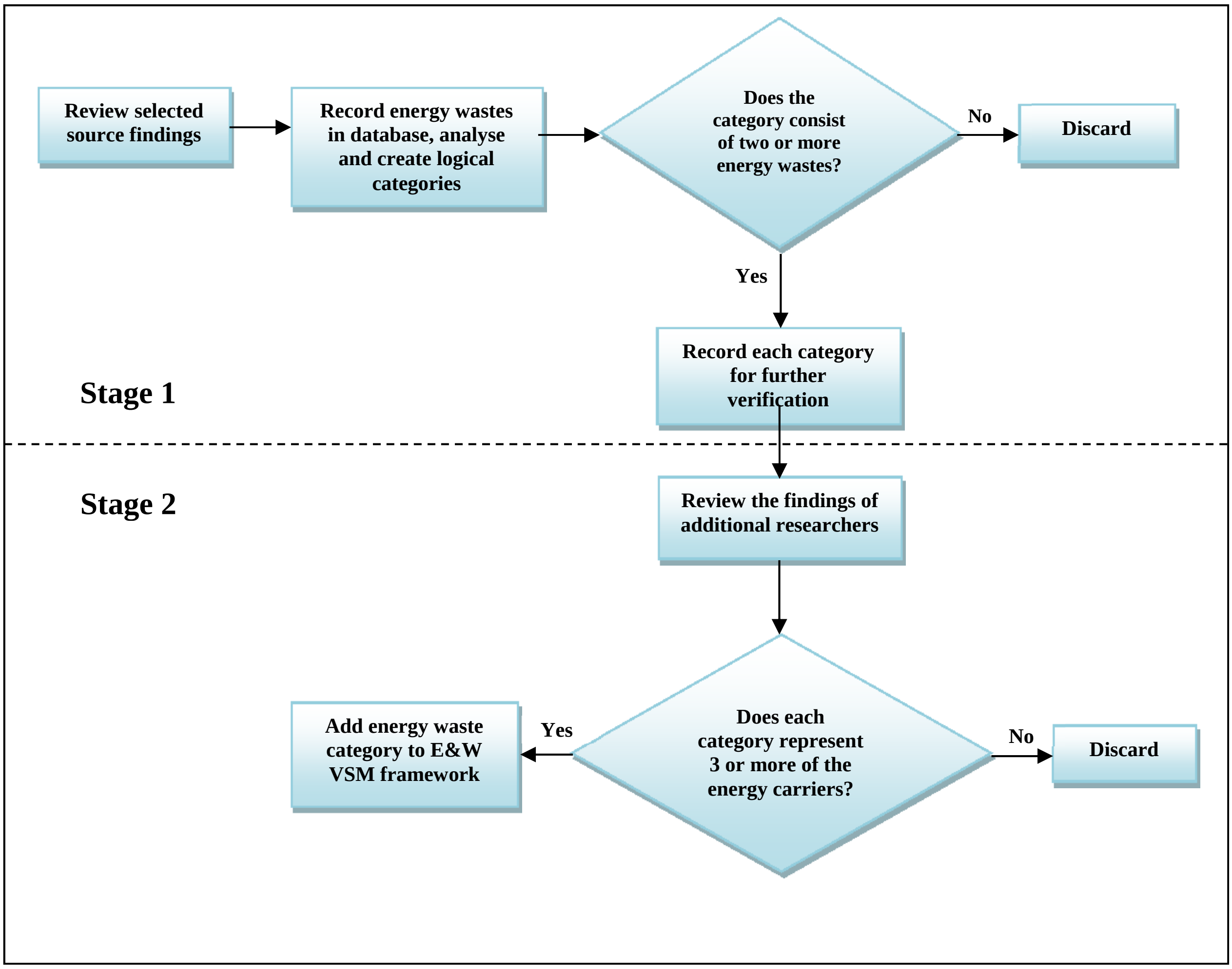

Figure 4. Flowchart of the decision making process constructed to establish the novel Lean water and energy waste categories

Sources included for the selection process were obtained from Journal publications, conference proceedings and books. In stage 1 of the decision making model described in Figure 4, the several source findings with regards to energy wastes were reviewed and recorded in a database. After reviewing all the sources, logical generic waste categories were formed. Only the categories which consisted of at least two waste types were considered. Stage 2 functions as a verification platform. Additional sources had to be collected to support the filtered waste categories. Before the final waste categories were established, each waste category were considered once more and had to represent at least 3 of the energy categories in order for it to be considered adequately representative. The result of this process is shown in Table 2.

Table 2. Grouping of energy wastes per category as a result of research

Energy Waste Category	Energy Waste	Energy Carrier
Leaks	• Steam leaks	Oil products, Electricity, LPG, Biomass, Coal, Water
	• Air leaks	Electricity , Coal
	• LPG leaks	LPG
Equipment sizing	• Oversized motors • Oversized HVAC systems • Improper air compressor size	Electricity
	• Over sizing of steam traps	Oil products, LPG, Biomass, Coal, Water
Idle time	• HVAC running during non-operation • Lights on during non-operation • Water circulation pumps running during non-production	Electricity
	• Engine systems running during non-production	Oil products
	•	
Engineering management	• Low power factor • Lack of variable speed drives • Lack of occupancy sensors • Inefficient motors	Electricity
Heat loss	• Improper furnace or boiler insulation • No heat recovery from coolant waters, ovens • Un-insulated ovens, kilns, heater bands on extrusion	Oil products, Biomass, Coal, Water

The five new Lean energy and water waste categories which were established are *leaks*, *equipment sizing*, *idle time*, *engineering management* and *heat loss*. These newly established waste categories will be used with the Lean based water and energy efficiency tool as discussed in the next section.

Lean based water and energy efficiency tool

The main objective of this study is to provide the manufacturing industry with a framework which can be utilised by its Lean and water and/or energy efficiency practitioners. It is expected that it should be able to be used both as a stand-alone tool as well as in conjunction with other existing Lean or water and energy efficiency programs within an organization.

The Lean tool which utilises and combines most of the other Lean tools and techniques is Value Stream Mapping (VSM). For this reason the VSM tool was chosen as the foundation for the proposed Lean based water and energy efficiency tool. VSM is a graphical tool which visualises information about the manufacturing process in a logical manner. The value stream of the current situation is usually observed in person and thereafter drawn by the Lean practitioner in order to create a map of the current situation, referred to as the current state map. The information required for the map is gathered by following a basic methodology as described by Rother and Shook (2003) in their book *Learning to See*. The current state map is then analysed and the proposed (improved) process flow with planned improvements is drawn on the future state map, which becomes a blueprint of the improved process.

The research process followed to develop the framework for the proposed *Water and Energy Stream Mapping (WESM)* tool is discussed in detail below.

Stage 1

Rother and Shook's (2003) VSM framework was used as the basis for the WESM framework. This provided the WESM framework with a systematic flow required to create a visual map. It was also decided that the framework will be specifically designed with the intention of being used as a continuous improvement tool, therefore following the Plan Do Check Act (PDCA) flow with a feedback loop.

Stage 2

Subsequent to creating the outline for the framework, it was decided to further analyse two internationally proven water and/or energy efficiency related frameworks. The frameworks chosen were the Measurement and Verification Methodology (USDoE, 2002) and Energy Audit framework (EMSD, 2007). After analysing these frameworks the elements appropriate to the delineation of study were highlighted and considered for inclusion in the framework.

Stage 3

In the final stage all the filtered elements were scrutinised by means of a logic check. The logical questions posed are listed below:

- Does the element fall within the delineation of study?
- Can the element be executed by either a Lean practitioner or water and energy efficiency practitioner within an organisation without outsourcing?
- Is the element executable in any manufacturing sector?

The elements which passed the logic test were included into the WESM framework. Figure 5 shows the flowchart of the novel EWSM framework that was developed.

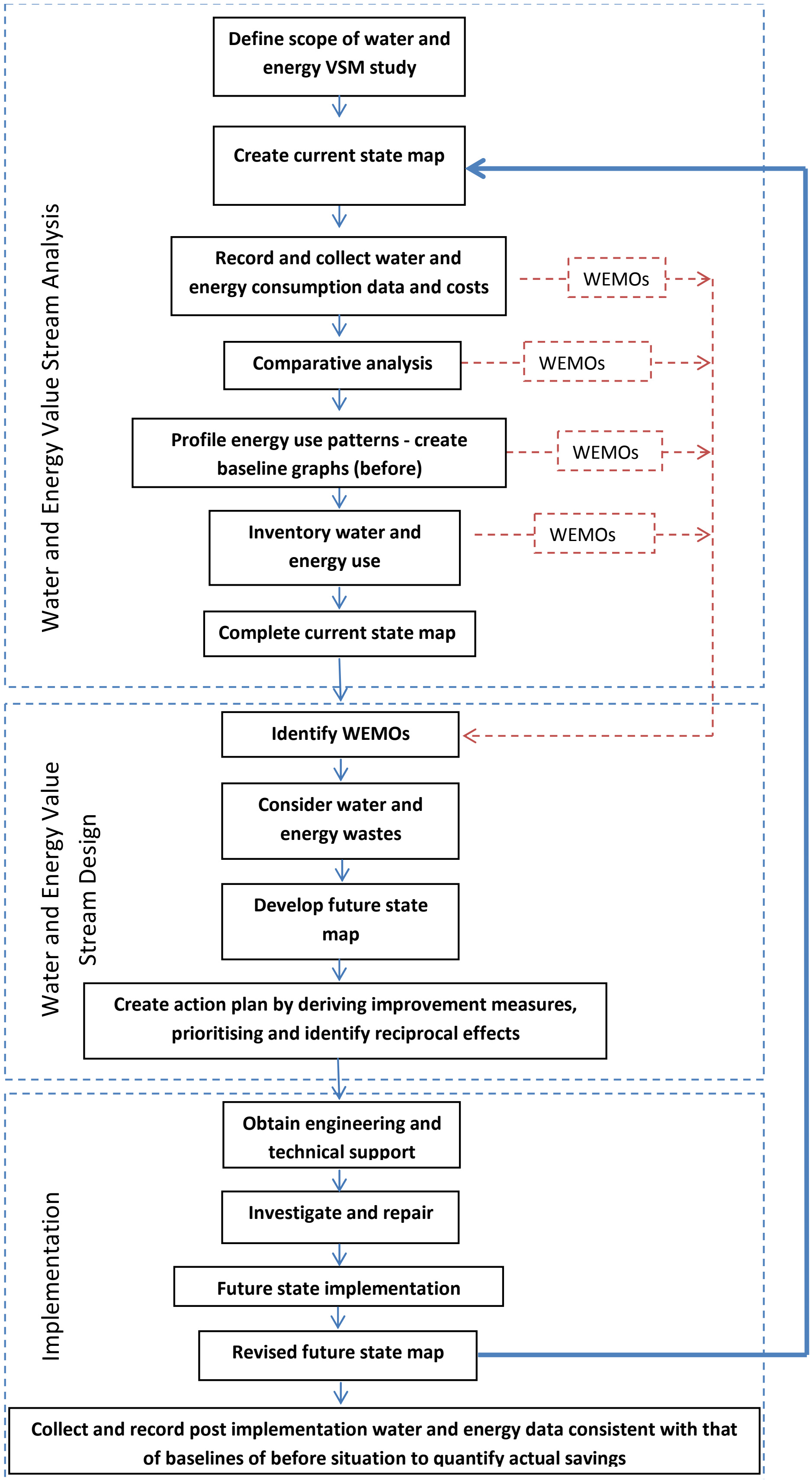

Figure 5. A flowchart illustrating the developed EWSM framework

WESM Framework

The three main phases of the WESM framework are the *analysis* phase, the *design* phase and the *implementation* phase.

In the *analysis* phase the scope of the study should be the point of departure. The next step will be to start with the creation of the current state map. This will allow the practitioners to physically identify and trace the water and energy use streams in their defined area of study. Any available water and energy consumption data should be collected at this point of the framework and if no such data exists (or additional data is required), this data should be physically recorded for a defined period of time. When the data is available and is being analysed, a comparative analysis to other similar areas should be conducted to ascertain if there are any opportunities to standardise a process over multiple areas or adopt a best practise from another area. The energy usage baseline graphs of the current state of the workshop should then be established. All water and energy usage per process should be catalogued at this point, where after the current state map could be completed. Throughout the analysis phase water and energy management opportunities (WEMOs) should be identified.

In the *design* phase the previously identified WEMOs are compiled in order to be considered for the future state map. The water and energy wastes (as established in this study) are considered at this point for the purpose of the completing the future state map. After the completion of the future state map an action plan should be created with the improvement measures, priority levels and timing. It is also important to note any area where reciprocal effects may be possible to maximise impact of the workshop, as well as to standardise across the organisation.

The final phase of the framework is the *implementation* phase. At this stage the WESM process is complete; however it is critical that the improvements are successfully implemented. Therefore any engineering or technical support which is required should be involved in the implementation phase. Any WEMO identified in the analysis phase where repairs or further technical investigation were required, should be performed before implementation of the complete future state map. In order to complete the PDCA phase for continuous improvement, the implemented future state map becomes the current state map for the next workshop in the studied area. It is important to continue to collect and record water and energy use data for the purpose of quantifying the water and energy efficiency improvement after the WESM intervention.

Conclusions

This paper discussed the challenges the South African manufacturing industry faces with regards to water and energy consumption.

The author believes that a *kaizen* approach to water and energy efficiency by utilising Lean techniques and tools will yield greater savings in the long term, than ad-hoc efficiency improvements. The literature review has revealed that a by-product of the implementation of Lean manufacturing techniques in the manufacturing industry has been the natural improvement of energy efficiency.

Subsequently the author embarked on the development of a framework for a Lean water and energy efficiency tool. The unique contributions made to the field of Operations Management resulting from this study are listed below:

- The formation of five additional standardised Lean waste categories specifically associated to water and energy wastes, namely *leaks, equipment sizing, idle time, engineering management* and *heat loss*.

- A systematic framework for the application of the WESM tool to be used in the manufacturing industry by Lean and/or energy efficiency practitioners.

Currently the newly established Lean wastes and the framework can be readily utilised in conjunction with the VSM tool. The next phase of this study will focus on adapting the VSM tool to maximise the water and energy savings potential, therefore creating a “sister” tool to VSM, hence named WESM.

Future work will consider the plausibility of developing a mathematical model to estimate the conservative water and energy savings possible when using the WESM framework.

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