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Development of a Framework for a Lean based Water and Energy Efficiency Assessment Tool

Edward Davies[1] and Karl van der Merwe[2]

[1]Doctoral Student, Department of Industrial Engineering, Nelson Mandela Metropolitan University, PO Box 77000, Port Elizabeth, 6031, South Africa, E-mail: davies@vwsa.co.za (corresponding author).

[2]Head of Lean Unit, Department of Industrial Engineering, Nelson Mandela Metropolitan University, PO Box 77000, Port Elizabeth, 6031, South Africa, E-mail: karl.vandermerwe@nmmu.ac.za

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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 and a brief discussion on the forecasting model incorporated.

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

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1. 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). Fig. 1 shows the electricity tariff increase of each year, from 2000 to 2014, in comparison to the year before (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 South African companies to become more energy efficient, especially since tariff increases have been higher than annual national inflation levels since 2003 (Ramokgopa and 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 Fig. 1). This has forced manufacturers to reduce their energy consumption and increase their process energy efficiency.

Fig. 2(a) and 2(b) 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.

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 (Den Heijer and Grobler, 2010). 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.

2. 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."

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 Fig.3.

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 et al., 2006). The energy benefits are summarised in Table 1.

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 within a process. The waste of water and energy has been mentioned and noted as Lean wastes by authors within Lean literature (Bicheno and Holweg, 2009; Nicholas, 2010; Seryak et al., 2006), however, these wastes have not been expanded and formulised into sub-categories, which refers to the root causes of these wastes respectively. 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. These standardised sub-categories of water and energy wastes will aid the Lean practitioner and project team to identify sources of wastes in the manufacturing process, just as the seven basic Lean wastes were intended to do.

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.

3. 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 Fig. 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. This assumption was based upon consideration of the viscosity and boiling point properties of that of liquid based fuels (such as petroleum, LPG and oil) and water. The above mentioned properties of water fall within the range of the various types of liquid fuel type energy carriers (SAIT, 2006).

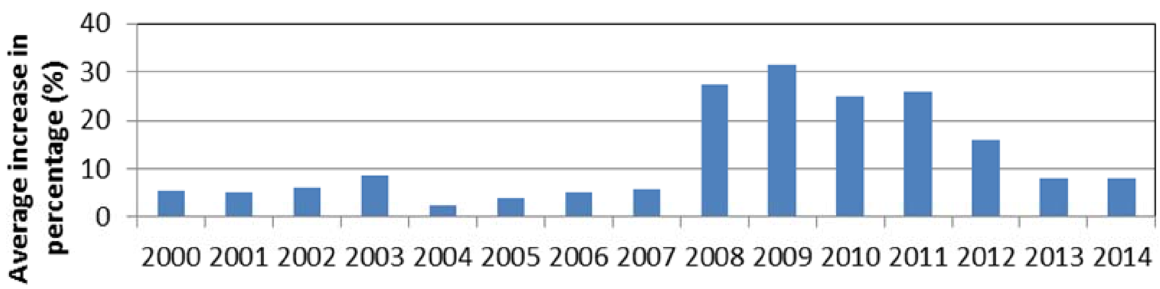
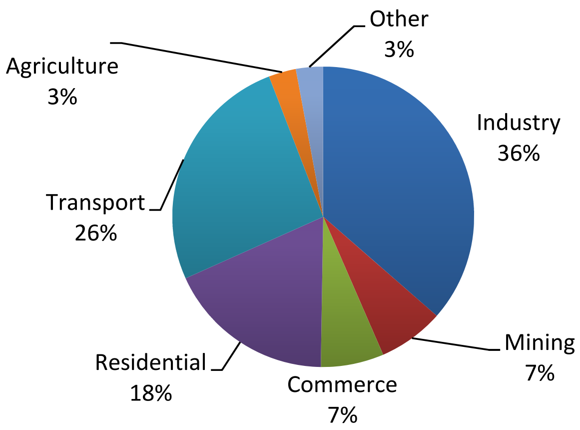
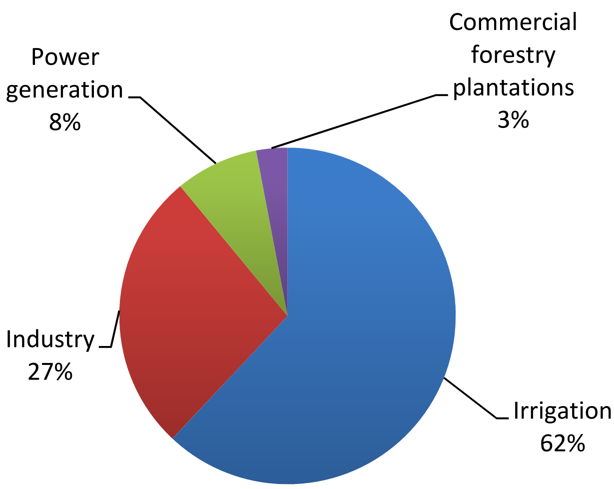


Fig. 1. Eskom's (South Africa's main energy utility) average annual electricity tariff increases from 2000 to 2014 plotted in percentage (Eskom, 2014)



(a) Breakdown of the final energy use by sector (DOME, 2009)



(b) Water use by major sectors in South Africa for 2004 (DWAF, 2004)

Fig. 2. Energy Consumption in South African

Sources included for the selection process were obtained from Journal publications, conference proceedings and books (Bergh, 2012; Blackmer, 2001; Kissock et al., 2001; Muller and Papadaratsakis, 2003; Turner and Doty, 2007). In stage 1 of the decision making model described in Fig. 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.

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.

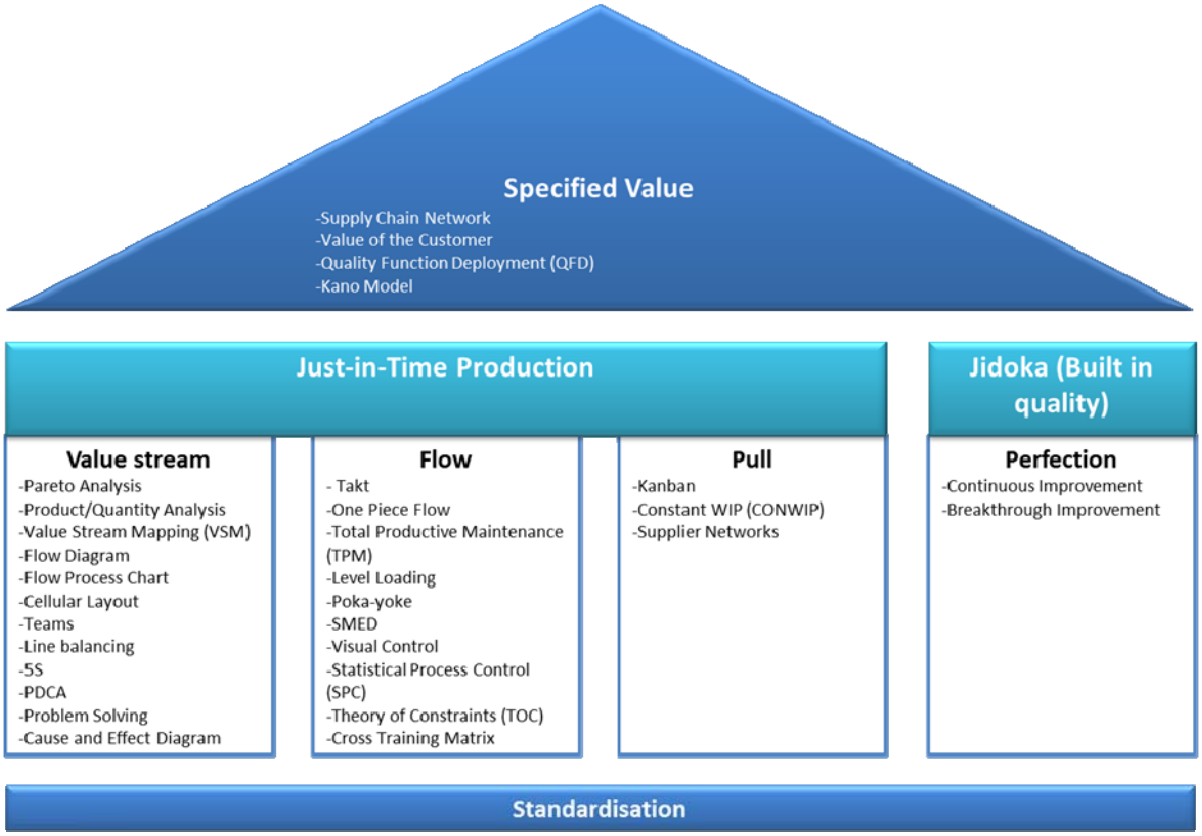


Fig. 3. Illustration of the five Lean principles with its respective tools and techniques listed underneath each pillar (constructed from Womack and Jones (2003) and Bicheno and Holweg (2009))

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 dependent 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 dependent equipment remains the same for increased output, decreased idle time for production dependent equipment and decreasing cycle times may increase equipment operating efficiency.
Increased throughput	Production equipment dependent 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 rework.
Part travel reduction	Decrease in WIP, thus shorter travel times resulting in decreased usage of energized equipment (conveyor belts, monorails, and vacuum tubes).
Space reduction	Decreased use of lighting and ventilation due to reduced open floor space.

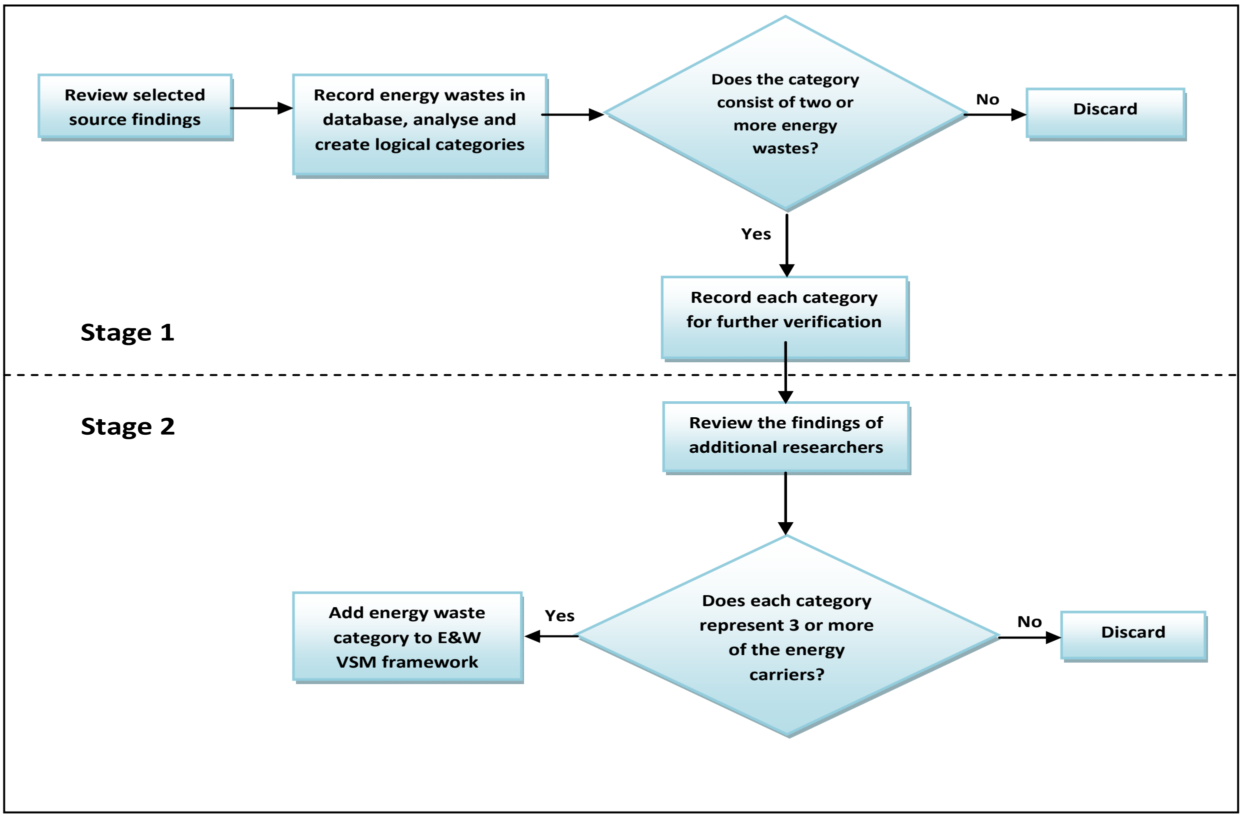


Fig. 4. Flowchart of the decision making process constructed to establish the novel Lean water and energy waste categories

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

4. 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 Lean practitioner will act as a facilitator during this process in order to get the involvement of a team of specialists from various departments and disciplines within the manufacturing process. The team will collectively assess the current situation and will be involved in developing the future state map, as they are the process owners and will have to ensure the long term sustainability of the proposed improvements. The theme of employee involvement and empowerment is one that is fundamental to Lean thinking (Nicholas, 2010; Morrey, Pasquire and Dainty, 2013; Van der Merwe, 2011) and this creates a culture where respect for people is created.

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.

4.1. 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.

4.2. 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.

4.3. 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. Fig. 5 shows the flowchart of the WESM framework that was developed.

5. 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.

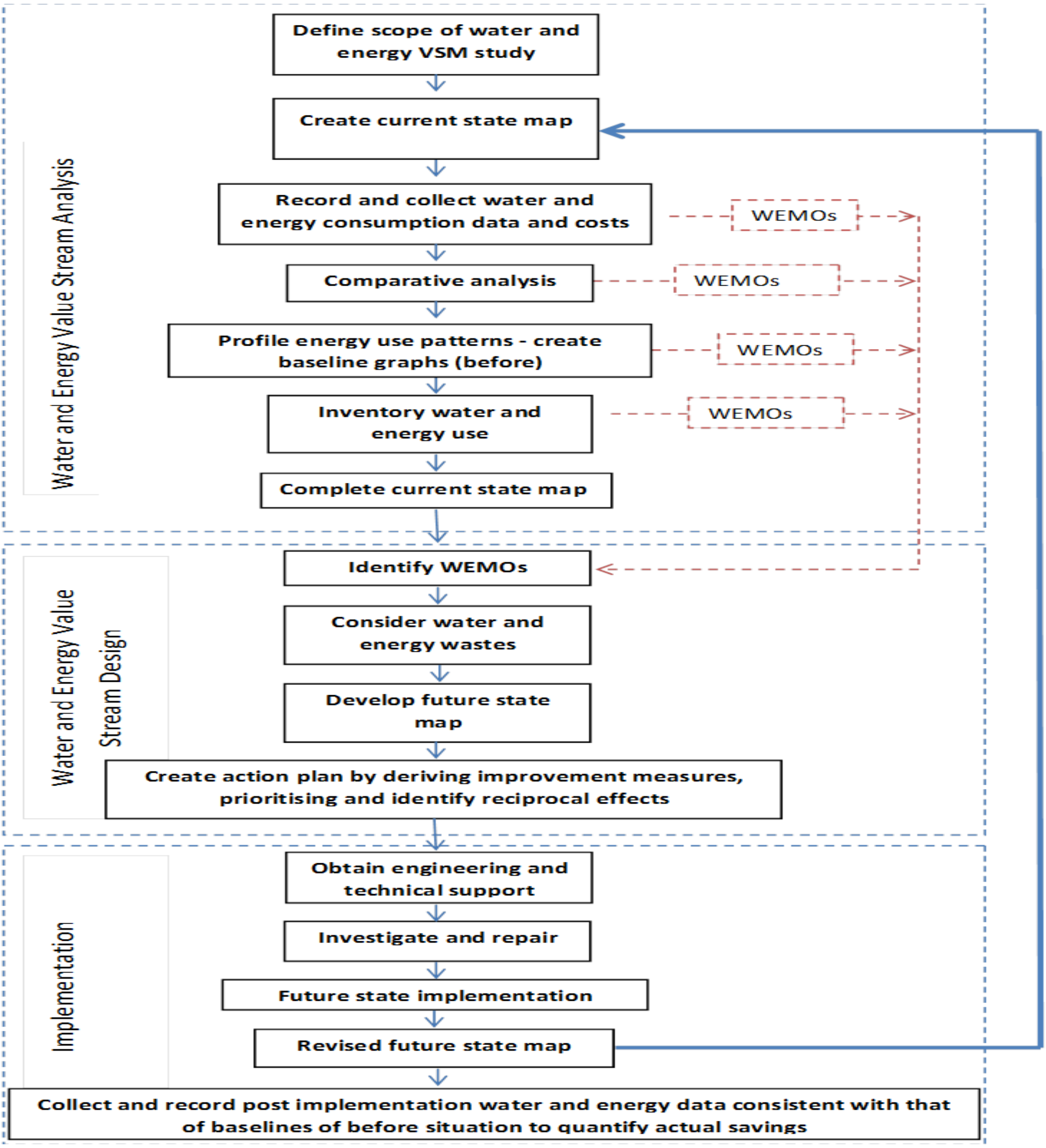


Fig. 5. A flowchart illustrating the developed WESM framework

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.

6. Forecasting Methodology

The forecasting methodology suggested to be used in conjunction with the WESM framework is explained in this section below. This methodology is similar to the one used by energy efficiency practitioners in Measurement and Verification projects (Den Heijer and Grobler, 2010; USDoE, 2002) and has been verified to yield successful results (Bosman and Grobler, 2006; Gouws, 2009; Masopoga et al., 2009).

In order to evaluate the effectiveness of a WESM intervention, the practitioner would have to compare the actual water and energy consumption data for a predetermined period of time of the post-implementation setup versus the pre-implementation setup, as shown in Eq. (1). The two elements in the WESM framework that ensures that the baseline data and post-implementation data are recorded for this purpose are *Profile energy use patterns – create baseline graphs (before)* and *Collect and* *record post implementation water and energy data consistent with that of baselines of before situation to quantify actual savings*. Adjustments are made if there have been changes to the baseline conditions after the initial baseline calculation (Den Heijer and Grobler, 2010).

$$E_{savings} = E_{baseline} - E_{posti-implementation} \pm Adjustment \quad (1)$$

Due to the unpredictable nature of the manufacturing environment, simply comparing the pre-implementation data for a specific period of time versus the post-implementation data will yield incorrect results which could lead to incorrect conclusions. It is therefore necessary to create a simple forecasting model, which can be used to forecast what the energy and water usage would have been for the identical manufacturing conditions as the actual measured post-implementation conditions.

The statistical technique used to develop the forecasting model is regression analysis. Regression analysis is a statistical technique used to estimate the correlation between various variables (USDoE, 2002). In order to create a simple forecasting model to predict the dependant variable (water or energy), the only independent variable taken into consideration is the production volume of the area in the intervention. Therefore the model is represented as in Eq. (2), where E represents the dependant variable (water or energy consumption), x represents the independent variable (production volume), B is the coefficient of the independent variable and C is the constant term.

$$E = B_1 x_1 + C \quad (2)$$

An indicator used to determine whether the regression model is acceptable or not is the correlation coefficient *R*, which measures the strength and direction of the linear relationship between two variables (Haaland, 1989). As we are not particularly interested whether the correlation is positive or negative, the R^2 value is used as a guide. A R^2 value greater than 0.75 is considered a strong correlation between two variables (Haaland, 1989).

Once the forecasting model for the WESM project has been created, the actual energy and water usage data can be compared to the forecasted usage and the effectiveness of the WESM intervention can be determined.

7. 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.

A forecasting methodology was also discussed which can be used in combination with the WESM framework in order to determine the effectiveness of the WESM intervention.

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 include the measurement and evaluation of the effectiveness of the WESM tool when used in the manufacturing industry.

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Edward Davies is currently completing his Doctoral studies in Operations Management at Nelson Mandela Metropolitan University, South Africa. He holds a Master's degree in Electrical Engineering, received from Cape Peninsula University of Technology and works at Volkswagen Group South Africa as a Regional Aftersales Manager. He is an associate member at the South African Institute of Industrial Engineering. His research interests include Lean management and energy efficiency.

Dr. Karl van der Merwe is a senior lecturer at the Department of Industrial Engineering and head of the Unit for Lean Process Development at Nelson Mandela Metropolitan University, South Africa. He is a member of the South African Institute of Industrial Engineering as well as the Engineering Council of South Africa. His research interests include Lean Process Development and Lean culture.