A Review of Integration Models for Industry 4.0 And Lean Management

Bongumenzi Mncwango
Department of Industrial Engineering
Durban University of Technology
Durban, South Africa

Kemlall Ramdass
Professor in Industrial Engineering
University of South Africa
Johannesburg, South Africa

Abstract

Lean management has been implemented successfully to improve efficiency in supply chain processes. With the progression and implementation of Industry 4.0, there is an increase in digitization actions to focus on greater business results and productivity. Major organizations are focusing on implementing Industry 4.0 initiatives in supply chain processes to advance efficiency and productivity. It is uncertain whether the implementation of industry 4.0 applications is in line with existing continuous improvement techniques such as lean management, which is known to have benefits in advancing business objectives. Therefore, this research is important in further exploring the synergies and practical implementation of both Industry 4.0 & lean management. This review looks at the practical applications of lean management and eleven industry 4.0 digitization enablers. The critical review of selected journal articles highlighting practical applications of the concept and integrative models was done to look at the integration models within industry 4.0 (horizontal, vertical & end-to-end engineering integrations) and challenges in adoption of the integration models. It further reviews the model of integration of lean management and the three industry 4.0 integrations and how they can be combined together in a practical manner for organizational benefits.

Keywords
Lean Management, Industry 4.0, Digitization, Integration Models

Introduction
Lean management has been implemented successfully to improve efficiency in supply chain processes. With the progression and implementation of Industry 4.0, there is an increase in digitization actions to focus on greater business results and productivity. Major organizations are focusing on implementing Industry 4.0 initiatives in supply chain processes to advance efficiency and productivity. However, the organizations must note that there cannot be a sudden switchover to Industry 4.0 initiatives, as there are management methods such as lean management that have been implemented. An integrated approach is necessary.

Lean management, traditionally, has been used in the manufacturing world but recently there has been a move to apply lean manufacturing principles in supply chain management. The indication by Santos (2019) further stresses the point that lean thinking organizations implement lean manufacturing with the aim of eliminating waste in production processes. Waste can take form of anything over than the minimum required amount of equipment, materials, parts, and working time that are essential to production (Santos 2019). The types of wastes that are being reduced are, overproduction, waiting, transporting, over processing, unnecessary inventory, excess motion, defects (Fercoq et al. (2016). Plattform Industrie 4.0 (2022) defines as follows "Industrie 4.0 refers to the intelligent networking of machines and processes for industry with the help of information and communication technology". Another definition of Industry 4.0 is " is a strategic approach for integrating advanced control systems with internet technology enabling communication between people, products and complex systems" (Anderl 2014). Schmidt et al. (2015) also describe Industry 4.0 as the snowballing digitization and automation of the manufacturing environment as well as the creation of a digital value chain to enable the communication between products and their environment and business partners

(Schmidt et al. 2015). The common concepts in these definitions are connectivity, integration and digitization, entrenching that they are important for Industry 4.0. According to Kolberg and Zühlke (2015), Industry 4.0 aims at optimizing value chains by implementing autonomously controlled and dynamic production. By this means, it could complement the established lean production systems to match future requirements. The implementation of Industry 4.0 has a vast potential and its application include focused industry-specific solutions, increased competitiveness and flexibility as well as increased organizational productivity (Mrugalska and Wyrwicka 2017).The key concepts underpinning Industry 4.0 are smart manufacturing, smart supply chain, smart product, Internet of Things (IoT), artificial intelligence (AI), augmented reality (AR) and virtual reality (VR) (Spoehr et al. 2020), (Sniderman et al. 2016).

Since Industry 4.0 is a fairly recent approach, therefore integrated implementation of industry 4.0 applications with lean management is recent, and it is thus important to assess whether it aligns well with existing continuous improvement techniques. This research is important in further exploring the synergies and practical implementation of both Industry 4.0 & lean management, in order to avoid contrasting actions in implementing lean management and Industry 4.0 initiatives. The research will focus on existing implementations of Lean Management and Industry 4.0 applications and review the models for integration of both management approaches in order to suggest a seamless integrative approach that organizations can implement.

2. Literature Review

In order to form a concrete background on the integration models of Lean and industry 4.0, it is critical to first do analysis of practical applications for these concepts. The literature survey looks at the peer reviewed journal articles with a synopsis of what was done during the implementation of each element of the concepts.

2.1. Lean Management applications

In addition to the practical case studies above Monteiro et al. (2017) used Lean Office tools and a technique called Action-Research to analyze existing logistics department processes. The methodology as described by Susman and Evered (1978), include 5 stages: diagnosis, planning actions, implementation, evaluation and specifying learning. The study achieved its objectives by reducing wastage, achieving transparency, clear identification of tasks and responsibilities of each employee. This can be adapted to assist with role & task identification, as well as allocation in logistics activities.

Table 1. Literature related to practical application of lean management

Study Reference	**Title**	**Synopsis**
(Smętkowska and Mrugalska 2018)	Using Six Sigma DMAIC to improve the quality of the production process: a case study.	The study used the DMAIC (Define-Measure-Analyse-Improve-Control) to identify problems with the production cycle of the company. They measured the historical data for the efficiency of the production machine. Using brainstorming, they analysed the data and classified it into categories of work, method, man, and machine. They then implemented the Single Minute Exchange of Dies (SMED) to reduce the downtime of the machine during changeovers. The control phase is to audit the changes implemented in the process and its impact and review changes continuously.
(Farsi et al. 2020)	An Optimisation Framework for Improving Supply Chain Performance: Case study of a bespoke service provider	The study validates an optimization framework for improving service supply chain performance using DMAIC cycle. They used a bespoke service provider was used to evaluate the applicability of the framework. This included identifying KPIs for different supply chain elements and links. This study contributed to the current research by developing a performance optimization framework for service supply chain using DMAIC cycle.

(Nandakumar, Saleeshya, and Harikumar 2020)	Bottleneck Identification and Process Improvement by Lean Six Sigma DMAIC Methodology.	The study used Six Sigma DMAIC in a food processing company to reduce bottlenecks and non-conformance in production and packaging processes. In the define phase, the study used SIPOC (Supplier Input Process Output Customer) to identify the problems. For the measure phase, they used VSM (Value Stream Mapping) to indicated nonvalue adding activities. In the analyses phase, they used statistics using one way ANOVA statistics. In the improve phase, the causes of bottlenecks were identified using Ishikawa diagram (cause and effect diagram) and devising an action plan. They identified strategies in the control phase continuously improve the process.
(Acero et al. 2019)	Order processing improvement in military logistics by Value Stream Analysis lean methodology	This study used Value Stream Mapping (VSM) and Define-Measure-Analyse-Improve-Control (DMAIC) to reduce the order processing time.

3.1.1. Industry 4.0 applications

This section relates to the sub-question on Industry 4.0 and its applications for continuous improvement. The Chartered Institute of Procurement and Supply (2019) identified eleven digitalization technologies that the organisations and institutions use to transform existing supply chain and procurement practices in manufacturing systems, forming the foundations of Industry 4.0. They form a fundamental basis of existence for Industry 4.0 and its connectivity. The eleven technologies are 3D printing, artificial intelligence, augmented reality, internet of things, RFID, robotics, omni channel, sensor technology, simulation, cloud computing and big data.

3.1.2. Radio frequency identification technology (RFID)

The use of smart tags with RFID can be explored by the asset management departments for tracking and can be integrated with app-based tracking. The architecture proposed by Bisio et al. (2016) can be adapted for implementation in an organization. The adaptation of the steps of evaluation of the implementation of RFID is critical and Dovere et al. (2015) provide the explanatory steps in their review.

Table 2. Literature related to practical application of RFID

Reference	**Title**	**Synopsis**
(Bisio, Sciarrone, and Zappatore 2016)	A new asset tracking architecture integrating RFID, Bluetooth Low Energy tags and ad hoc smartphone applications	The authors explore the use of RFID and Bluetooth tags for asset tracking on construction sites. They integrated with the tags and smartphone applications through android applications for the search and track function.
(Dovere, Cavalieri, and Ierace 2015)	An assessment model for the implementation of RFID in tool management	In this paper, the authors offer an experiential model to gauge evaluating the cost benefits when implementing RFID use for identification.

3.1.3. 3D Printing

The establishment of 3D printing facilities in an organisation can assist with a sudden change of demand. This may ease pressure on the procurement process and reduce costs of manufacturing if implemented internally.

Table 3. Literature related to practical application of 3D printing.

Reference	Title	Synopsis
(Varsha Shree et al. 2020)	Effect of 3D printing on supply chain management	The study looks at the use of 3D printing or additive manufacturing and its impact on supply chain management. It emphasises the importance of suppliers using it for manufacturing components to reduce lead time by using fewer materials, less assembly steps. The study further denotes that 3D printing has been used in industrial products, specialised equipment, and others. This can be used in this procurement process in order to fast track the long lead time identified by the survey. By streamlining the manufacturing process, there is a great benefit in adopting the 3D printing of parts for the research equipment. A crucial point, which the authors also note, is that AM can be used to manufacture products closer to the customer, thereby potentially reducing the need for product shipping and reducing inventories.
(Xu, Rodgers, and Guo 2021)	Hybrid simulation models for spare parts supply chain considering 3D printing capabilities	The study focuses on the use of 3D printing in manufacturing spare parts by the United States Navy. The use of models for forecasting of the demand for the spare parts is a key part of the functioning of this Industry 4.0 enabler. The simulation model uses agent based, and discrete events to mimic the practical supply chain of spare parts. The key take in this study is the use of the 3D manufacturing facilities to manufacture spare parts on demand, thus reducing the risk of stock outs, and more importantly, it could reduce the need to carry expensive stocks of spare parts. In the procurement process of the university being studied, having 3D printing facilities will assist in ensuring adequate inventory, even with a sudden growth of demand.

3.1.4. Augmented Reality and Virtual Reality

The use of AR and VR can be used to visualize the product and correct specifications of items can be clarified before the product is manufactured or delivered. In this way, the products can be correctly delivered and installed quicker, thus enabling an efficient equipment setup.

Table 4. Literature related to practical application of AR and VR

Reference	Title	Synopsis
(Stoltz et al. 2017)	Augmented Reality in Warehouse Operations: Opportunities and Barriers	This paper discusses the benefits from using AR in distribution centres. The authors experimented with the use of Google Glass (wearable technology) for various warehouse operations such as picking, shipping, and packing. Among others, the benefits were reduced error rate, expanded operator flexibility without using handheld scanners, improved picking accuracy and Avoiding unnecessary movements.
(Krasyuk and Fedyakov 2020)	AR/VR Technologies And Their Applications in Procurement	The paper evaluates various literature around the use of Virtual Reality and Augmented Reality in the procurement environment. The overall benefits in the summary of literature include simplification and clarification of requisition documents, elimination of defective product purchase, proper elucidation of customer needs.

3.1.5. Artificial Intelligence

Artificial Intelligence (AI) is defined as the capability of a machine to display smart human capabilities such as intellectual, knowledge, design and ingenuity (European Parliament 2020). According to Riahi et al. (2021), AI further empower systems to make practical decisions and perform activities automatically without human involvement. The organisations and institutions can then exploit AI for insights in supply chain functions such as demand forecasting, customer management, warehousing, logistics, and procurement.

Table 5. Literature related to practical application of Artificial Intelligence

Reference	Title	Synopsis
(Kiefer et al. 2019)	Application of Artificial Intelligence to optimize forecasting capability in procurement	The paper emphasize the extent Artificial Intelligence can be used for improving the demand forecast accuracy in supply chains. The authors further compare AI models with traditional statistical models that are static. The AI models in the study performed better in determining the accurate and up to date forecast.
(Chopra 2019)	AI in Supply & Procurement	The use of Artificial Intelligence elements in supply chains is discussed by the authors. Block Chain, which is an element of AI, can be used to track and trace the digital footprint of a product or part from the primary producer to any party involved in the value chain. The use of programmatic buying has made the initially complex procurement processes to be instantaneous by using the analysis of complex combinations of data, online veritable data, stakeholders and machine learning systems. The authors endorse the improvement of the skillset of professionals in the IT support systems and procurement. This skillset would be related to data & AI science.

3.1.6. Big data

An online bidding system for price negotiation can be used by the initiators of requisitions and suppliers for faster quotation process. RFID Tags to monitor stock and demand forecasting of products that are frequently utilized. This will inform the assets and warehouse team to trigger an automatic request for stock requisition as to avoid stock outs. A risk mitigation strategy can be derived from the Big Data analysis for frequently utilized suppliers.

Table 6. Literature related to practical application of Big Data

Reference	Title	Synopsis
(Mastos et al. 2020)	Industry 4.0 sustainable supply chains: An application of an IoT enabled scrap metal management solution	The paper looks at the application of IoT in the scrap metal and waste management processes. The study proposes a real-world application of IoT in supply chain. The shop-floor bins were fitted with IoT sensors, real time monitoring for fill levels, data visual system for optimization of planning tasks as well as an online bidding (price negotiations for scrap dealers and waste management companies).
(L. Wang and Alexander 2015)	Big Data Driven Supply Chain Management and Business Administration	The authors review Big Data applications in supply chain management, its applications, and pitfalls in achievement of business objectives. They further elaborate on how Big Data application can assist in the elements of a supply chain i.e., better forecasting by demand and supply chain planning, location tracking using RFID. Incorrect data or "dirty data" coupled with data privacy policies preventing full sharing can be a major challenge toward optimal implementation and use of Big Data for business objectives
(Hung, He, and Shen 2020)	Big data analytics for supply chain relationship in banking	In this study the authors use big data to analyse supply chain relations for credit reports and e-wiring transactions for its Business to Business (B2B) partners. The study further portray how big data analysis can provide solutions for the marketing campaigns and risk management.
(Fan, Heilig, and Voß 2015)	Supply Chain Risk Management in the Era of Big Data.	This paper provides a novel framework that uses Big Data to develop an effective supply chain risk management system for stochastic environments.

3.1.7. Cloud Computing

Table 7. Literature related to practical application of Cloud Computing

Reference	Title	Synopsis
(Jones 2015)	Cloud computing procurement and implementation: Lessons learnt from a United Kingdom case study	In this case study, Cloud Computing was deployed to reduce procurement costs and advance political ambitions of implementing CC by the government. The grounded theory was used for the qualitative research (interviews with staff). After triangulation of the responses, it was evident that the implementation of cloud computing was successful and yielded benefits such as increased resilience, sharing of resources and improved agility. This implementation also mitigated risks such as Poor performance and Service unavailability.
(Singh et al. 2014)	Cloud computing technology: Reducing carbon footprint in beef supply chain	In this case study, cloud computing was used to integrate the segregated segments of a beef supply chain with an aim to reduce the carbon emissions throughout the value chain. In this pilot study, the model identifies the carbon hotpots in the value chain e.g., farm, logistics, slaughterhouse, processor and retailer and its associated carbon footprint. From the analysis screen, they can measure the carbon footprint and locate the improvement areas.

3.1.8. Internet of Things

From the synopsis above, for example, a company can implement an online system that can be used by the requisition initiators and procurement team to understand the supplier lead times, historical delays and other related information before making a selection for service or product provision. Coupled with the sensor use promulgated by Mulay(2017), this can be an automated system using IOT analytics.

Table 8. Literature related to practical application of IoT

Reference	**Title**	**Synopsis**
(Abdel-Basset, Manogaran, and Mohamed 2018)	Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems	This research paper presents the use of Internet of Things (IOT) framework for supply chain management which based on IOT technologies. The authors propose a system to automate and address the existing supply chain problems and complexities. Using RFID technology, the flow of products was tracked throughout the value chain. The data obtained was linked to the supplier code and then made available to the store managers as to identify vital information about the supplier. The authors further propose a framework that integrates neutrosophic Decision Making Trial and Evaluation Laboratory (N-DEMATEL) with analytic hierarchy process (AHP) procedures to understand interrelationships for a smart supply chain.
(Mulay 2017)	Data Analytics Using IOT In Procurement	In this paper, the author proposes a model of implementing a smart eProcurement from a manual system. The author suggests computerization of the procurement process using sensors in products. These sensors would learn the insights on product utilization frequency embedded on the item master data. The sensor would then raise an automatic purchase requisition and purchase order. The author summarises by stating that "This learns from the dataset provided, analyse, draw insights and take intelligent decisions."

3.1.9. Omni Channel

As a suggestion, organisations can link omnichannel capability to the ERP system and suppliers of high value products or materials. This could allow virtual viewing rooms that the buyers (procurement team) can utilize to view functioning and suitability of the equipment before purchasing it. The BOPS capability can be integrated on the procurement process and system to reduce lead times and delivery delays.

Table 9. Literature related to practical application of Omni Channel

Reference	Title	Synopsis
(Park et al. 2021)	Showcasing optimization in omnichannel retailing	The authors propose a generalised high value products optimization model that can be used in various productions. This model supports the idea of a virtual showroom with big screens to assist with convening the product features so that consumers can visualize how the product will perform in reality, while saving a significant percentage of investment on a physical showroom.
(Kong et al. 2020)	The effects of BOPS implementation under different pricing strategies in omnichannel retailing	The authors profile the BOPS (buy online and pick up in store) system in different pricing strategies of omnichannel. The model and test used imply that there are significant savings that the consumer can realize by using this route of BOPS.

3.1.10. Robotic Process Applications

The integration of RPA software into the ERP system can be explored by companies to automate of tasks like creation and processing of purchase orders and invoice preparation. Further integration of chat bots in the ERP System, for the purchase requisition initiators for proper track and tracking and effective communication with the procurement team may also assist in improving supply chain efficiency.

Table 10. Literature related to practical application of RPA

Reference	Title	Synopsis
(Hartley and Sawaya 2019)	Tortoise, not the hare: Digital transformation of supply chain business processes	In this paper the authors analyse the digital transformation of supply chain processes. They explore the quick wins that Robotic Process Automation (RPA) can achieve for routine processes. They further state that the RPA tasks include data entry, simple mathematics, processing of data from ERP systems and filling of forms. The use of RPA software is recommended by the authors for automation of these tasks.
(Karumsi, Prokopets, and Clements 2020)	Automation in procurement: Your new workforce is here	KPMG company is a well-known global consulting entity and develops solutions for many companies. For the purposes of this study, the application of bots in procurement is chosen as an example. The company has implemented over six hundred bots in various industries and in processes such as customer support, purchase order conversion.

3.1.11. Sensor Technology

The smart sensors can be explored as a method to assist asset management to fast track their processes by allocating a sensor before the tagging and asset registration. This will then trigger the phone application to remind the asset registration team to follow up and complete item registration within time.

Table 11. Literature related to practical application of sensor technology

Reference	**Title**	**Synopsis**
(Fitzgerald et al. 2018)	Using smart sensors to drive supply chain innovation	The authors profile the applications that companies that have integrated smart sensors into manufacturing operations and asset management for tracking real times status of items.
(Osmonbekov and Johnston 2018)	Adoption of the Internet of Things technologies in business procurement: impact on organizational buying behaviour	The authors look at the application of IoT technologies in procurement. Technologies such as sensors and chips are stated as future tools for information gathering which may replace research surveys, supplier visits and equipment tests. With embedded chips, sensors and communications technologies, little funds will be spent on the traditional methods of data collection.

3.1.12. Simulation

From both studies in this simulation section, the models can be developed to imitate various scenarios. The results from the simulation studies can inform the procurement team to develop risk management strategies for extreme events that can disrupt the supply chain system. Furthermore, contracts renewal scenarios can be simulated to further inform decision makers.

Table 12. Literature related to practical application of simulation

Reference	Title	Synopsis
(Stich et al. 2016)	A Simulation Based Approach to Investigate the Procurement Process and Its Effect on the Performance of Supply Chains	The paper suggests the simulation of different procurement strategies and different manufacturing scenarios. This is done to easily analyse and choose cost- effective procurement strategy without practically evaluating the actual strategies. The simulations of supply chains are used in order to improve the production process. In this study they use simulation to test the factors impacting on the supply chain's performance.
(Kornevs, Baalsrud Hauge, and Meijer 2019)	Gamifying Project Procurement for Better Goal Incorporation	The authors suggest using a participatory simulation for investigation of different issues existing in road construction procurement and its complexities. They use the simulation to restructure procurement agreements based on different life cycle instances.

3.2. Relationship Between Lean and Industry 4.0

In their research study, Rüttimann and Stöckli (2016), argue that the benefits of implementing Industry 4.0 as a revolution will not be realised, but its elements have to be integrated into Lean framework for it to not fail. This is due to the fact that Industry 4.0 is dependent on the right applicability and makes Lean more flexible. Rüttimann and Stöckli (2016), further argue that Industry 4.0 provides enhanced technical capabilities for Lean (similar to the integration model of Sony (2018), but that Industry 4.0 and Lean may be most applicable for different types of companies (flexibility vs volumes). This affirms that there is a relationship between lean and Industry 4.0. Rossini et al. (2019) studied 108 European companies implementing Lean and commenced Industry 4.0 adoption at the same time, and found that higher Industry 4.0 implementation may be easier to accomplish when lean is extensively implemented in the organisation. The articles by Rüttimann and Stöckli (2016) and Rossini et al. (2019), study confirms that indeed, there is a strong relationship between the two approaches, as each becomes a catalyst of another during implementation

3.3. Affordability and Investment Requirements

There are costs associated with the implementation of any management approach in any company. While lean is aimed at reduction of production costs, creation of value and waste reduction (Rojko 2017), implementing Industry 4.0 may increase the initial capital expenditure on technological requirements. Sony (2020) supports this by stating that, although in the long term, the cost will breakeven, however, the initial cost of implementing Industry 4.0 is high due to cost of automation and the requirements of highly skilled labour. It is therefore important for organisations review the costs involved in implementing Industry 4.0 and lean in an integrated manner. The organisations may need to revise the scale of implementation, introducing elements of Industry 4.0 in an affordable manner, based on the affordability study.

4. Methods

For this review, interpretivism research paradigm was used. Interpretivism approach is of the view that individuals shape society and are not puppets to the external social forces (Ryan 2018). The approach argues the uniqueness of each individual; thus, scientific methods are not appropriate. Hence it involves in-depth investigations and takes a qualitative approach. The selection criteria for journal articles used for literature review was that articles must have been published in a peer-reviewed journal, proceedings or published government/company position paper. Critically, the paper must have been focusing on practical or applied case studies for lean management, industry 4.0. This was to highlight the importance of the underpinning concepts of industry 4.0 and lean management in the integrative models. The review of integration was limited to Industry 4.0 and Lean Management integrative model as well as integration within industry 4.0. There were no boundaries imposed on the field of the surveyed articles, however the focus was on supply chain applications for both the concepts of industry 4.0 and lean management. Figure 1 shows the number of articles that have been cited in this paper by year of publication.

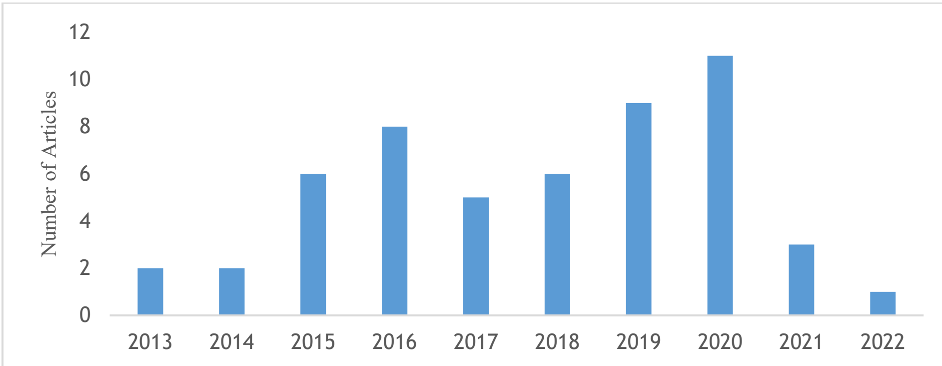

Figure 1. Article distribution by year of publication

5. Integration Within Industry 4.0

According to Wang et al. (2016), there are three kinds of integration in Industry 4.0 namely horizontal, vertical and end-to-end engineering integrations. This review study builds on two existing theories by validating the frameworks developed by Wang et al (2016) and Sony (2018). The need for validation specified by Soni and Kodali (2013), is addressed so that the gap between the theory and practice is bridged.

5.1. Horizontal Integration

Horizontal integration include synchronization of value networks to enable collaboration between companies in the supply value chain (Foidl and Felderer 2016). An example of horizontal integration, as provided by Foidl and Felderer (2016), is a supermarket chain sharing of demand forecast in a digital system to enable the producer to determine the required production volumes, and this. provides an accurate forecast which decreases variability from actual sales. The horizontal integration of all systems along the value chain benefits also enables customers are able to track the progress of their ordered product (Foidl and Felderer 2016). The horizontal model is evaluated for validity, reliability and objectivity by Foidl and Felderer (2016), and used to detect business gaps and opportunities to improve the industrial environment.

5.2. Vertical Integration

As described by Schildenfrei (2019), vertical integration deals with the integration of information systems in various organisational hierarchical levels between operations and management. Vertical integration comprises various hierarchical subsystems within the organization to create a flexible and reconfigurable manufacturing system within the organization (Wang et al. 2016). The autonomous interconnection of the systems is essential and can be achieved through a smart enterprise resource planning (ERP) system where Big Data plays a critical role in vertical integration (Foidl and Felderer 2016). The benefit of having a vertically integrated organisation using unified integration and interconnection of all different production processes and steps, the organisation can expects more transparency in their processes (Foidl and Felderer 2016). According to Schildenfrei (2019), the pitfall with vertical integration is that it is mainly focused at production and manufacturing environments, and this raised the need to further study how it can be expanded to include logistics environments such as warehousing and procurement. The other pitfalls include:

- scaling up of information technology systems and infrastructure – This is because Industry 4.0 utilizes large amounts of data and thus the need for fundamental IT capacity increases (Schildenfrei 2019).
- breaking down silos - Industry 4.0 integration levels require breaking down data and knowledge silos from all departments for optimal integration (Schildenfrei 2019).

5.3. End-to-end engineering integration

End-to-end engineering integration focuses on the production or provision of customized products and services across the value chain (Sony 2018).As described by Stock and Seliger (2016), end-to-end engineering integration is critical in enabling creation of customized products and services across the value chain .

6. Integration Models of Lean and Industry 4.0

From the three types of integrations within Industry 4.0, Sony (2018) developed models where lean management and Industry 4.0 can be integrated. They are

- Vertical integration and lean management
- Horizontal integration and lean management
- End-to-end engineering integration and lean management

Prinz et al (2018), argue that lean management, as a methodical approach, is a requirement for Industry 4.0. This is because LM is aimed at value creation through optimizations and standardization while Industry 4.0 is realized by the application of technologies. The earlier study by Mrugalska & Wyrwicka (2017) asserted that lean production benefits the production companies and manufacturing systems by creating value, reducing waste, and producing good quality products, and improving customers' satisfaction. They further state that in order to achieve full flexibility of production systems, the integration of information communication technology to the production, planning, customer, and supplier levels is necessary. Sony (2018), proposes a model of integrations for lean and Industry 4.0 and propositions for implementation to test its robustness. The 15 detailed propositions suggested Sony (2018) provide a solid base for implementation and recommendation on how these integrations can assist the business with a blueprint for implementing both lean and industry 4.0 simultaneously.

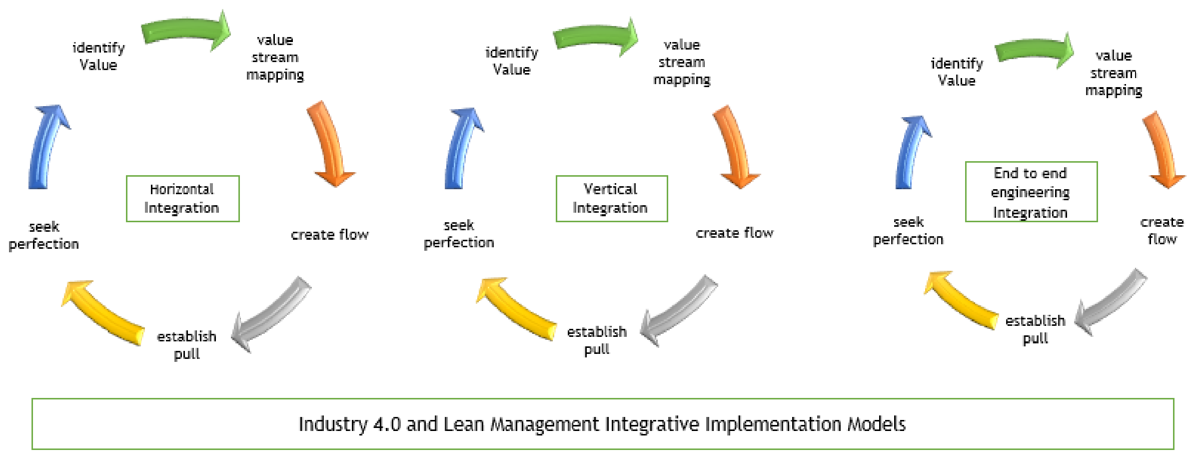

Figure 2. LM and Industry 4.0 Integration (Source: (Sony 2018))

It is evident that these two approaches can coexist and support each other for advancement of business objectives. The application of this model industry may be modified for implementation. Since organizations have already implemented lean management, they may adopt the digitization solutions that come with Industry 4.0. For example, volatile customer demand can be mitigated by "heinjuka" or levelling in the lean management approach. This can be integrated with cyber physical production systems, which is a key component of Industry 4.0.

7. Discussion And Conclusion

This review provides an understanding of the integration models for lean management and industry 4.0 applications. There are three types of integrations that can be employed to integrated applications of Industry 4.0. They are vertical integration, horizontal integration, and end to end. These models of integration are proposals by Wang et al (2016) and are built on Kagermann (2013).The constructs of these integration models form a firm foundation for building on other continuous improvement techniques including lean. The challenges in adoption of vertical integration model for Industry 4.0 include scaling up of information technology systems and infrastructure due to that Industry 4.0 utilizes large amounts of data and thus the need for fundamental IT capacity increases (Schildenfrei 2019). The challenges with vertical integration within Industry 4.0 also entail breaking down silos as Industry 4.0 integration levels crucially require breaking down data and knowledge silos from all departments for optimal integration (Schildenfrei 2019).

The integration model of lean and Industry 4.0 proposed by Sony (2018) is built on Wang et al. (2016) model, and includes the integration points of lean management with all the three integration of industry 4.0 which are vertical, horizontal integration as well as end-to-end engineering integration models. Sony's theoretical model is more structured and robust. The application of this model industry may be modified for practical implementation since organizations have already implemented lean management, they may adopt the digitization solutions that come with Industry 4.0. Sony (2018), further provides 15 propositions that can be used to implement lean and Industry 4.0 applications in an integrated manner.

The research by Rüttimann and Stöckli (2016), suggest that the implementation of Industry 4.0 implementing should be approached in a practical manner, slowly integrating its elements in lean management, as to avoid failure. The study by Rossini et al. (2019) in 108 European companies show that Industry 4.0 adoption catalyses the benefits of lean management when implement extensively. An important factor of cost implications is raised by Rojko (2017), and Sony (2020) concurs by stating that there will be high costs of implementing Industry 4.0, such as automation and high skilled labour requirements. This raises the need for organisations to do affordability studies and determine the scale and manner of integration for lean and Industry 4.0. From the propositions and models of integration discussed above, a combined approach for implementation can be formulated by adjoining the foundations of problem solving (Figure 3).

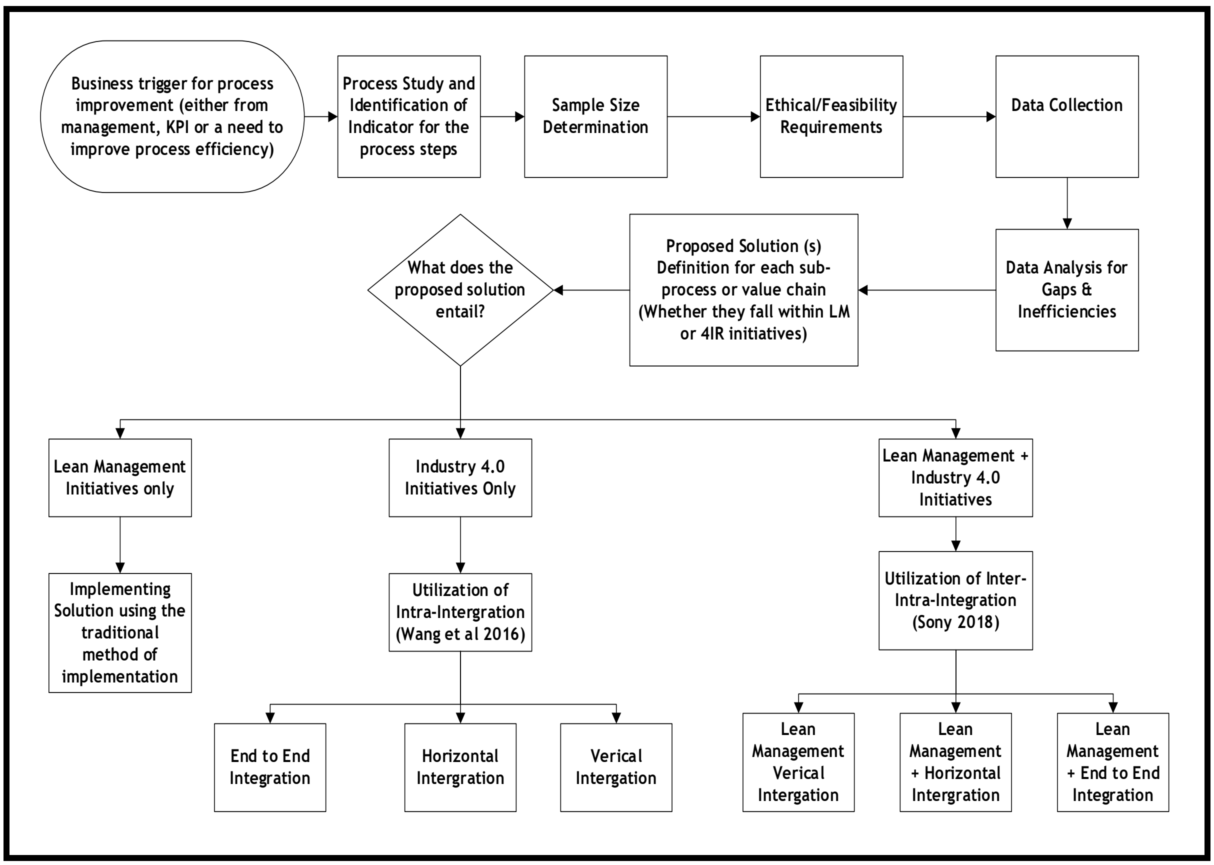

Figure 3. Integrated model of implementation , Adapted from Wang et al. (2016) and Sony (2018)

The review of the models contribute by proving a blueprint that can be followed to implement integrated problem-solving approach and identifying synergies in implementing both Industry 4.0 and lean management as to avoid contrasting actions. It also provides a basis for testing the practicality of the integration models by Wang et al. (2016) and Sony (2018). It forms a foundation for validating the constructs of integration models and an opportunity to make dynamic additions or deletions for further improvement. The applications within lean management and industry 4.0 can are clearly detailed in the case studies, however the integrated implementation has not been documented much in the journal articles. It is therefore important to study the models of implementation explained in this review, for testing and validation in practical operational process settings as to improve the models. The evaluation of costs in implementing these integrative models is critical for comparison with the previous costs of non-integrated implementation as for further validation, return on investment and benefits.

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Biographies

Bongumenzi Mncwango is currently completing his PhD. He obtained his BTech in Industrial Engineering from the Durban University of Technology and MSc in Management and Optimization of Supply Chains and Transport from Ecole des Mines de Nantes, France. He is a member of the Southern African Institute of Industrial Engineering (SAIIE). He enjoys lecturing and interacting with students at all levels of study.

Prof Kem Ramdass has worked as a work-study officer, industrial engineer, production/operations manager and skills development facilitator in the clothing, electronics, and textile industries between 1981 and 1999. He joined the academic profession in 1999 as a lecturer with Technikon South Africa. He later moved to UNISA'S Department of Business Management in 2006 lecturing in operations management. He is currently a Professor in the Department of Industrial Engineering based at Unisa, Florida Campus. He has a passion for quality and firmly believes that the application of quality management methodologies will highlight deficiencies and instigate the implementation of improvement strategies. He has applied continuous improvement methodologies from an industrial engineering, quality, and operations management perspective. He is a process, performance, and operations specialist with a driving passion for improving production, quality, and competitiveness. He has authored and presented approximately 50 journal and conference papers both nationally and internationally and is a peer reviewer for numerous publications. He has achieved Fellow member status at SAIIE and is a member of PICMET and IEEE. He is registered as Pr Tech Eng at ECSA and is appointed as a member of the Code of Practice Steering at ECSA.