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Review article

Review of life cycle models for enhancing machine tools sustainability: lessons, trends and future directions

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ABSTRACT

The life cycle models are critical in the assessment of the performance of a product from the design phase to its end of life (EoL). With the quest for manufacturing sustainability with respect to energy, process, material, and environment friendliness as well as the clamour for circular economy which emphasizes zero tolerance for waste, there is a need for a critical review of the life cycle of machine tool employed for machining operations and product development. The objective of this study is to evaluate the efficient way of managing the machine tools throughout its lifecycle. Several studies have been conducted in analysing the life cycle of the machine tools and different strategies were employed for its design, manufacture, use, maintenance and recovery at the end of life. The common approach to ensure environmental sustainability was established when comparing the literature studied. From the articles reviewed 60% applied life cycle assessment (LCA) methodology to reduce energy consumption and enhance environmental sustainability, while 40% employed other assessment tools. In this study an integrated life cycle and cyber physical machine tool model is proposed.

1. Introduction

The 21st century is characterised by vast technological changes, with many manufacturing industries faced with the challenge of developing cost effective products and innovation which will not only meet customer needs but also address the environmental issues. The term "Life cycle" can be defined as a closed cycle process with several stages within the cycle (Peña et al. 2021; Finnveden et al., 2009; Guinee et al., 2011; Guinée and Heijungs 2000; Klöpffer, 1997; Hauschild et al., 2018; Hellweg and Canals, 2014; Pennington et al., 2004; Reap et al., 2008; Simonen, 2014; Horne et al., 2009). The various stages are given a specific name to differentiate it from one another, these stages move flawlessly and frequently to the next stage with no pause in between the stages Matthews et al. (2014). On the other hand, life cycle model is the beginning of the key concept of systems engineering which comprises of series of stages that are guided by several management decisions which qualifies the system to be well established to progress to the next stage of the system's life cycle (Peña et al., 2021). However, there is no single system that is a one size fits all, such that it so versatile that it can be applied in all environments, each system coins its own life cycle model based on the characteristics and the needs of the industry. Material recovery at their end of life will assist in preventing of waste generation which contributes to the negative environmental impact at the product's end of life. Machining refers to the removal of material from a work piece during manufacturing in order to impart in them the desired shape (Cao et al., 2012). Machine tool is a machine that is used to shape or construct a metal by cutting, boring, grinding or as per the intention of the user. They are normally heavy and consists of components, clamps, etc. that are required to conduct a certain work or job. Manufacturing companies mostly depends on these machines for products manufacturing (Mayr et al., 2012; Boothroyd, 1988; Vijayaraghavan and Dornfeld 2010; Koren, 1997; Mori et al., 2011; Uriarte et al., 2013; de Lacalle and Mentxaka, 2008; Neugebauer et al., 2007; Youssef and El-Hofy, 2008). The examples of machine tools include; lathe, drill press, milling machine, screw machine, etc as depicted in Figure 1. The machines tools can further be classified into dedicated machine tools (Landers et al., 2001; Mayr et al., 2012; Chanal et al., 2007; Xu and Newman, 2006; de Lacalle and Mentxaka 2008; Koren, 2006; Valdes et al., 1997; Huang et al., 2010; Bringmann et al., 2014), Flexible machine tools (Browne et al., 1984; Stecke, 1985; Mori and Fujishima 2009;Kostal &Velisek 2010ElMaraghy, 2005; Patpatiya et al., 2021; Cook et al., 2020; Oshel et al., 2020) and Reconfigurable machine tools (Ding et al., 2021; Xing et al., 2021; Kumar

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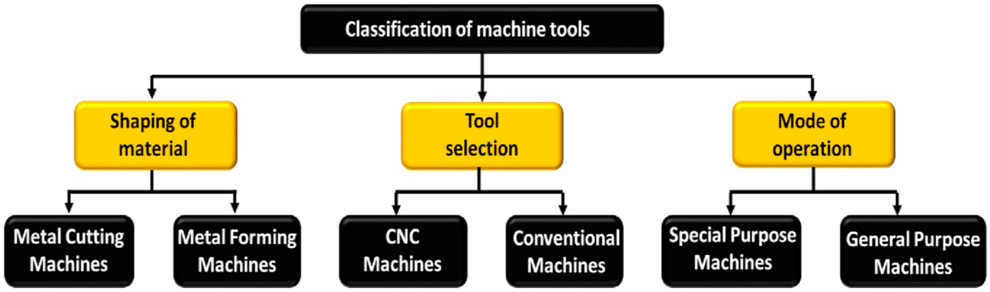

Figure 1. Classification of machine tools.

et al., 2021; Mahmoodjanloo et al., 2020a,b; Huang et al., 2020; Ming et al., 2020; Bruzzone et al., 2020; Wang et al., 2020; Wang et al., 2018; Gadalla and Xue 2018; Olabanji and Mpofu 2020; Murena et al., 2017; Battaïa et al., 2017). The classification of machine tools is shown in Figure 1. According to Cao et al. (2012), the machine tools are basically employed to create a pre-determined shape on work piece material and to provide diverse services in the industry necessary for the processing of the components parts.

Duflou et al. (2012) highlights the machine tools as tools necessary for imparting the desired shape in a material in order to meet the geometrical and dimensional requirements of the final product on a specified structure. The impact of the machine tools on the environment is considered as the most critical factor during the use phase of a Life Cycle Assessment (LCA), because machine tools induces energy during operation (Santos et al., 2011; Hu et al., 2012; Akbari et al., 2001; Zein et al., 2011; Zendoia et al., 2014; Vijayaraghavan and Dornfeld 2010; Azevedo et al., 2011; Azkarate et al., 2011; Zhou et al., 2016; Hwang et al., 2009; Geissdoerfer et al., 2017). According to Diaz et al. (2010) activities in the manufacturing industry accounts for 19% of the world's greenhouse gas emissions. In the United States manufacturing industry is responsible for the total energy usage of 31%. Recently, the machining in manufacturing has been targeted to reduce energy. The need to create awareness with regards to environmental protection and the possible impact of the machine tool development throughout its lifecycle has necessitated the need for the assessment of its lifecycle. This will enhance better understanding about the impact of each stage of the machine tool development on environment. Besides, the LCA of machine tools will provide an insight into the possible ways by which the impacts can be minimized. Figure 2 depicts a conceptual overview of the life cycle stages of a machine tool beginning with the material extraction right through to the waste management and the recovery process in a circular loop in order to promote the concept of circular economy.

The LCA addresses the potential environmental impact resulting from a product development and throughout its life cycle (ISO, 2006). The life cycle starts from the design phase and runs through the manufacturing, usage and end of life. Hence, a product's life cycle represent the birth to the end of life, and re-birth, which creates a cycle (Gao and Wang, 2017). It promotes proper design, use and reuse of the product to minimize negative environmental impact. The significance of LCA to this study is that it helps to determine the environmental impact of all the stages of machine tool from the design to the end of life. The stage with the most significant contribution to the environmental impacts will also be determined. The understanding of the environmental impacts will enhance the development of sustainable solutions to reduce the environmental impacts associated with the stages of the machine tool as part of present or future directions. Some of the sustainable solution may include: redesign, reconfiguration, as well as adoption of a suitable end of life options. The concept of circular economy is a proven tool for sustainable manufacturing. The concept has the capacity for improving environmental sustainability, material and energy efficiencies

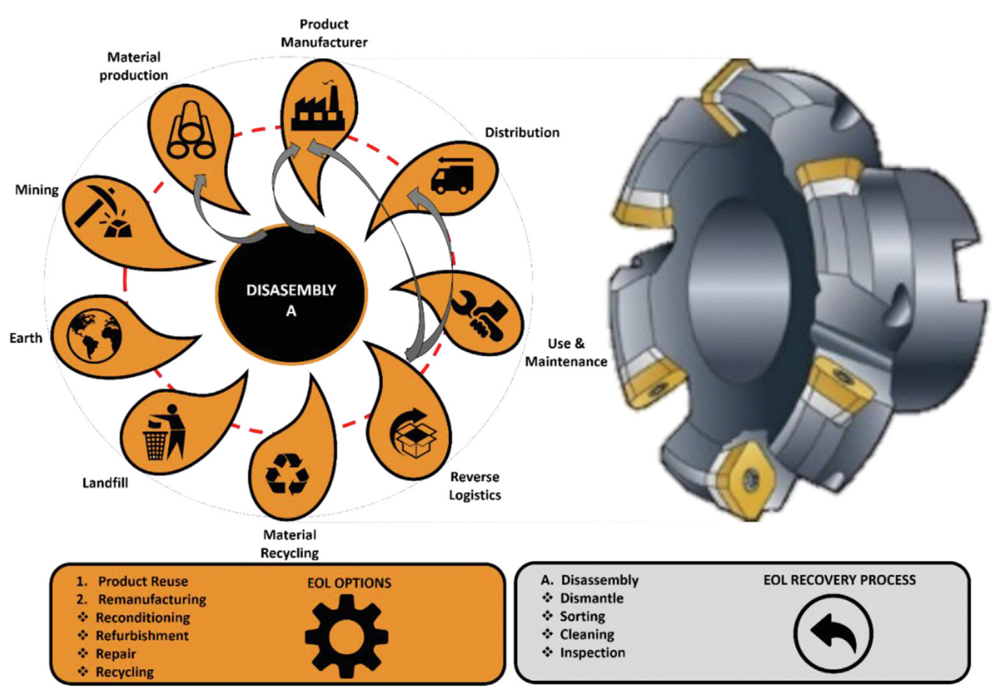

Figure 2. Conceptual view of the life cycle of a machine tool (Adapted from Duflou, 2008).

throughout the lifecycle of a product. Circular economy adopts end of life options such as recycling, reuse, refurbishment etc. to minimize waste and reclaim materials o products into useful service after the end of their useful life (Jawahir and Bradley, 2016; Murray et al., 2017; Wu et al., 2014; Geissdoerfer et al., 2017; Peña et al., 2021). Figure 3, depicts a product at it's to end of life (EoL) with the possible (EoL) options to reclaim it back into service. As shown in Figure 3, with the EoL options, the product can be reclaimed wholly back into service, or remanufactured for the emergence of a new product. The product can be reused, remanufactured, recycled, refurbished, repaired or reconditioned depending on the condition after the inspection at the end of its life. The stages create a cycle which allow the materials or products to be used again, in order to prevent the generation and indiscriminate waste disposal. Phuluwa et al. (2019), proposed a demanufacturing model for reclaiming products back into useful service after their end of life.

The manufacturing industry which is applicable to machine tools has experienced an increase in production and competitive pressures from their processing, this is due to the globalization and individualization within the manufacturing industry. These pressures are fueled by the growth of the new generation which mainly focuses on information technology through manufacturing. In addition to the concept of circular economy earlier discussed, intelligent manufacturing is one of the most important elements of the new industrial revolution, which is the digital networking and intelligent development of the manufacturing industry.

Another one is the sustainable manufacturing. This is one of the most important process to be adhered to in this era of uncertain global economy. This manufacturing involves the development of products through processes that are environmentally friendly, energy and resources efficient. Sustainable manufacturing has been defined as development of products via processes with optimal energy and natural resources conservation, and minimal negative environmental consequences for employees, communities, and consumers (Ball et al., 2009; Branker et al., 2011; Loglisci et al., 2013; Lee et al., 2014; Yi et al., 2015; Gupta et al., 2016; Li et al., 2017). The quest to develop smart products which will meet functional requirements using emerging materials within a short manufacturing cycle time has led to increase in energy requirement of the manufacturing processes with environmental impact and cost consequences (Priarone, 2016). Typical examples of such emerging materials are the nickel-based super alloys, for instance, the Inconel 718, Grade EA1N steel, Gamma and Beta titanium based alloys amongst others (Koohestani et al., 2014; Fratila, 2014; Daniyan et al., 2020a).

These materials boast of excellent mechanical properties such as high strength to weight ratio, excellent fatigue and creep performance, good corrosion resistance ability, coupled with their suitability for high temperature applications which makes them suitable as an alternative to the steel based alloys (Kara and Li, 2011; Mhamdi et al., 2012; Pervaiz et al., 2013).

They find suitable applications in the biomedical, railway, aerospace, automobile manufacturing industries most especially in areas where special properties are required to meet the service or functional requirement of a component or sub assembly (Kara and Li, 2011; Mhamdi et al., 2012; Pervaiz et al., 2013; Koohestani et al., 2014; Fratila, 2014; Daniyan et al., 2020b). The limitation being the low thermal conductivity which causes the material to retain heat rather than dissipating it, thus, making the manufacturing process less sustainable (Rashid et al., 2012; Shokrani et al., 2016; Ayed et al., 2017). In order to promote effective manufacturing, cost and environmental sustainability, different strategies are employed for the implementation of sustainable machining processes. These includes: process modelling, simulation and optimization, effective lubrication, redesign and reconfiguration of tool and the use of the hybrid machining process. These are to promote cost effectiveness, energy, material and environmental sustainability with improved productivity (Dhananachezian & Kumar, 2011; Lee et al., 2012; Elshwain et al., 2013; Strano et al., 2013; Djavanroodi et al., 2013; Courbon et al., 2013; Rotella et al., 2014; Park et al., 2015; Kant and Sangwan, 2015; Kishawy et al., 2019; Shan et al., 2019). The quest for a sustainable manufacturing process whilst keeping a clean environment has necessitated manufacturers to develop and implement sustainable manufacturing processes with low carbon footprint and optimum energy and material consumption. The optimization of the machining parameters is necessary in order to promote effective energy consumption and minimize carbon emissions. The need to meet the dynamic nature of the

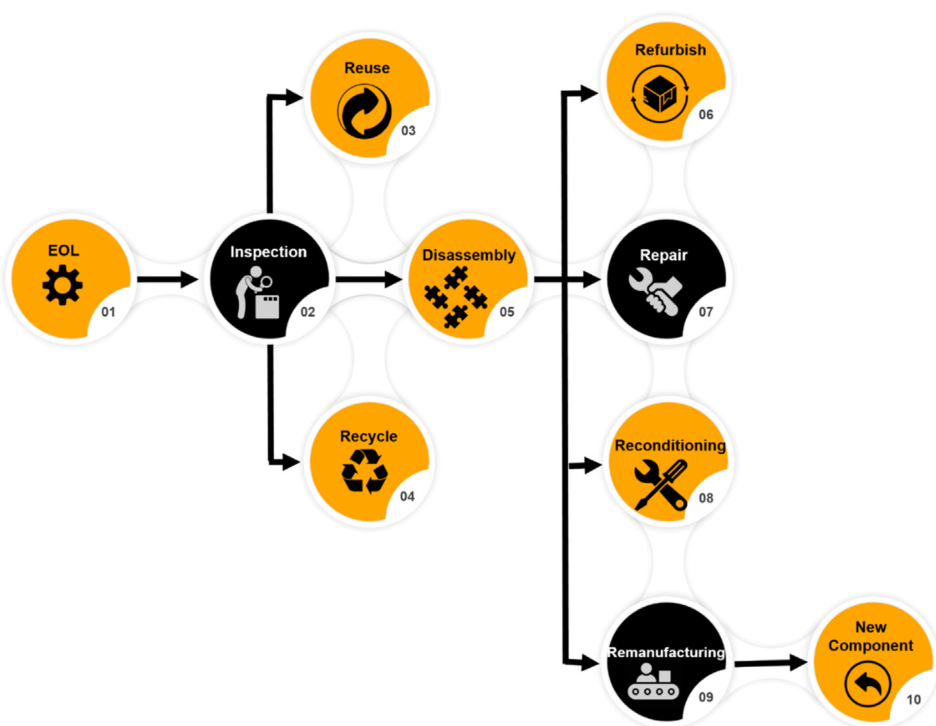

Figure 3. Sustainable model for product recovery (Modified from Phuluwa et al. 2019).

customers' service and requirements coupled with the development of emerging materials have contributed to the social, economic and environmental challenges including global warming, waste generation and indiscriminate disposal. There is therefore the need for the optimization of the energy, and material consumption in order to reduce carbon emissions and environmental which starts with the holistic review of the product's and machine's life cycle. The assessment is necessary in order to achieve significant reduction of carbon emissions in the machine tools industry and prevent pollution and its associated environment impact, which is widely believed to contribute to global warming. There are different approaches or techniques that the machine tools industry can follows in order to produce efficient products. The focus of this study is on machining of products' and the machines' life cycle. The aim of this work is to review existing models used in the machine tool industry, thus, making recommendations aimed at ensuring that product manufacturing and machine tools operations are conducted in a way that it will enhance cost, material and environmental sustainability. The novelty of this study lies in the fact that a literature survey for the enhancement of machine tools throughout their life cycles which captures different machine tool life cycle enhancement approaches has not been sufficiently reported by the existing literature. Some of the approaches captured in this study include: LCA principles for low carbon manufacturing, life cycle inventory and impact assessment, reconfiguration of manufacturing systems, Internet of Things (IoTs) and web-based applications, computer aided process planning and cloud platforms, software tool, life cycle oriented services, life cycle costing and profit approach, preventive structuring approach, tool and equipment management approach, technical product service system (t-PSS), real time monitoring approach, green cutting technology, remanufacturing modelling and optimization approach, and multi-criteria decision approach. Thus, in this study an integrated life cycle and cyber physical machine tool model which takes into account all elements and stage of life cycle is proposed. The structure of this study structure consists of extensive literature review, discussion of findings, as well as conclusions and recommendations based on the outcome of the studied literature.

2. Methodology

This study employs the search technique for the identification of the articles to be reviewed. The identification of the articles was followed by a comprehensive review and synthesis of the content of the articles. The study follow a systematic review provided in the work of Abdulrahaman et al. (2020) which involves identification of data sources for the search, keywords for the search as well as the inclusion criteria.

2.1. Data sources

Abdulrahaman et al. (2020) stated that the quality of a systematic review is a function of the data sources employed for the identification of the articles to be selected for the review. A thorough search of literature which relates to the focus of the study was carried from academic research databases. This was followed by the screening and selection of the articles in line with the study. The academic research database consulted include Directory of Open Access Journals (DOAJ), Science Direct, Directory of Open Access Repository (OpenDOAR), Researchgate, IEEE Explore, ACM Digital library, Google Scholar, Springer, Wiley Online Library, Taylor & Francis, EBSCOHOST, Web of Science, Semantic Scholars and Scopus.

2.2. Keywords search

The technique of keyword search as proposed by Kitchenham et al. (2009) and used by Abdulrahaman et al. (2020) was also employed in order to ensure that only relevant literature are obtained and considered in this study. Some of the keywords employed include: "Life Cycle Assessment of Machine Tools" "Sustainability of Machine Tools" "Machine tools" "Energy efficiency of Machine Tools" "Life Cycle Models of Machine Tools", End of Life of Machine Tools", Environmental Impact Assessment of Machine Tools" "Low Carbon Manufacturing" Machine Tool Life Cycle Inventory and Assessment" "Modelling and Simulation of Machine Tools" "Optimization of Machine Tools" "Reconfiguration of Machine Tools" "Green Manufacturing Technology" amongst others.

2.3. Inclusion and exclusion criteria

The inclusion criteria were based on the relevance of the articles to the study, year of publication, empirical results, and theoretical framework. Research articles that presented empirical results and theoretical explanations or framework about the topic of study whose year of publication lies between year 2000–2021 were selected. The year of publication was however not used as a basis of selection for seminar works, and textbooks.

The total number of the articles from the obtained from the database after the search was 12,987. Thereafter, papers that are not related in terms according to the title were eliminated. Furthermore, the elimination of duplicate papers (the same paper but from different databases) were carried out. This brought about the reduction of the articles obtained from 12,987 to 1780. Next was the elimination based on the content of the articles. Articles which provided empirical results, conceptual or theoretical explanations and frameworks about the life cycle models for enhancing machine tools sustainability including critical lessons, trends and future directions were selected. After the elimination process a total number of 150 articles were reviewed. The 150 articles are articles peer reviewed and published in reputable journals and conference proceedings and written in English language. The framework for the inclusion and exclusion of the articles is presented in Figure 4.

Table 1 presents the percentage of the articles obtained from each academic database for the final 204 articles reviewed.

3. Review of existing literature

The impact of unsustainable manufacturing processes in terms of manufacturing resources, energy consumption and environmental friendliness cannot be downplayed. Hence, the effective control of the manufacturing resources may help the manufacturing industries gain a competitive edge over others. Therefore, when designing a product, there must be an understanding of the actual design which will promote the

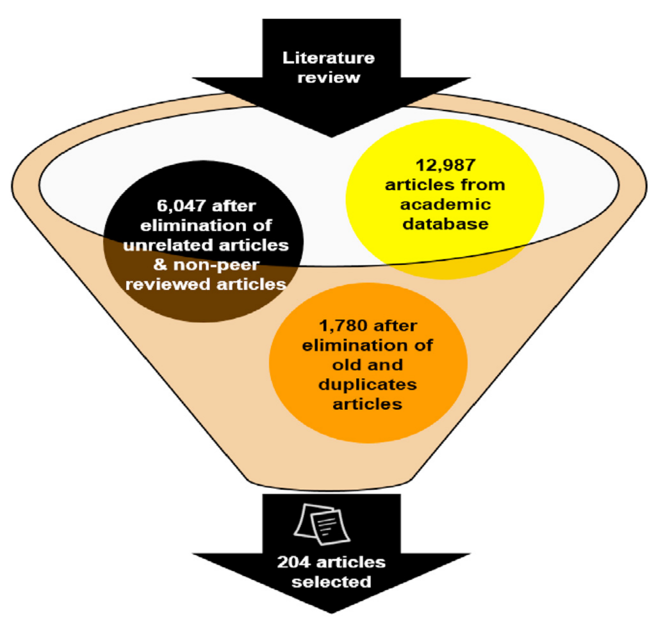

Figure 4. Framework for the inclusion and exclusion of articles.

Table 1. Percentage of the articles reviewed from academic database.

S/N	Data base	URL	% of articles
1	Directory of Open Access Journals (DOAJ)	https://doaj.org/	4
2	Science Direct	http://www.sciencedirect.com/	20
3	Directory of Open Access Repository (OpenDOAR)	http://roar.eprints.org/7031/	4
4	Researchgate	https://www.researchgate.net/	8
5	IEEE Explore	http://www.ieeexplore.ieee.org/	4
6	ACM Digital library	http://dl.acm.org/	2
7	Google Scholar	https://scholar.google.com/	8
8	Springer	http://www.springer.com/	18
9	Wiley Online Library	http://onlinelibrary.wiley.com/	6
10	Taylor & Francis	http://taylorandfrancis.com/	8
11	EBSCOHOST	http://ebsco.com/	2
12	Web of Science	https://apps.webofknowledge.com/	4
13	Semantic Scholars	https://www.semanticscholar.org/	2
14	Scopus	https://www.scopus.com	10

development of sustainable products (Lee et al., 2012). This is critical as it directly impacts the capabilities and technology used in the manufacturing system.

Raman et al. (2020) conducted a literature review on some manufacturing systems and processes such as hybrid/additive manufacturing, nanomanufacturing, system characterization methods, as well as human capacity development for advanced manufacturing industry. In the quest to achieve manufacturing sustainability, the authors presented the following recommendations:

- Improvements in sensing, controls, metrology
- The use of well-formulated algorithms, models, or techniques for the improvement of system and process level performance.
- The use of Artificial Intelligence (AI) for the enhancement of system and process level performance across manufacturing spheres.
- Improvement in trainings relating to manufacturing.

This study focusses on themes such as LCA principles for low carbon manufacturing, life cycle inventory and impact assessment, reconfiguration of manufacturing systems, Internet of Things (IoTs) and web-based applications, computer aided process planning and cloud platforms, software tool, life cycle oriented services, life cycle costing and profit approach, preventive structuring approach, tool and equipment management approach, technical product service system (t-PSS), real time monitoring approach, green cutting technology, remanufacturing modelling and optimization approach, and multi-criteria decision approach.

3.1. LCA principles for low carbon manufacturing

According to Cao et al. (2012), it is essential to promote the concept of low carbon manufacturing during various manufacturing system environment of machine tools. The authors describes LCA principles an approach/method as:

❖ *Design and manufacturing*: Process and product design and the use of manufacturing technologies followed by the assembly processes etc.
❖ *Use*: This is the operational stage of the machine tool which is usually energy intensive.
❖ *Transportation:* the source of transport that is required between the stages, such as car, truck, shipping, railway and other.
❖ *Remanufacturing*: The products can be reclaimed into use via recycling, reuse, refurbishment etc.

Cao et al. (2012) also describes the carbon efficiency indicators of machine tools as the production rate carbon efficiency, material removal rate carbon efficiency and economic return rate carbon efficiency. According to the authors, life-cycle carbon emissions can be categorized into two: the varied emissions and fixed emissions. The varied emissions range in different amount and effect by region due to different drivers and as a result corresponding countermeasures should be taken for different causes (Zheng et al., 2019). For fixed emissions, the amount and effect are usually stable over time according to region. The carbon efficiency indicators are developed to investigate the changing features of the varied emissions in relation to some variables such as: volume of material removed, production throughput and economic return. Huang et al. (2009) conducted the review of some of the existing LCA tools, and identified the knowledge gaps for the UK road industry. The study explained the development of a LCA model for asphalt pavement construction. Du et al. (2015) proposed a framework of low-carbon operation models and demonstrated the implementation using a machine tool industry as a case study. The authors established an investigative system framework of low-carbon operation models for machinery manufacturing industry. Burchart-Korol et al. (2016) presented a computational LCA model for the determination of the environmental impact of a coal mining processes in Poland. The methodology employed by Diaz et al. (2010) studied two types of machine tools applying LCA, namely the CNC milling machine (Bridgeport Manual Mill Series I) with a low level of automation and a Mori Seiki DuraVertical 5060 with a high level of automation. The predominant use of the two machines in the manufacturing industries were the basis for their selection for evaluation. The amount of energy consumed and carbon emitted were calculated during each life-cycle stage in different environments.

3.2. Life cycle inventory (LCI) and impact assessment

Zendoia et al. (2014) carried out a detailed description of a novel approach which demonstrates the applicability of LCA using two different manufacturing scenarios. The machine tool life cycle inventory approach is partly based on the guidelines defined in ISO/DIS 14955-1 (International Standard Organisation, 2019). One of the scenarios involves the development of an aeronautic part while the other involves the manufacturing of a component part manufactured for the household usage.

The indicators for the LCA of the component part manufactured for household that of the aeronautic application show the robustness of the new approach in their LCA.

The validation, applicability and performance of the LCA model of machine tools was performed using a new defined methodology. In the study, two case studies were conducted in the household manufacturing sector and aeronautic sector. The two sectors were compared with respect to their environmental impacts. In the household sector, the energy and materials as well as other variables were measured and recorded. A computer program based on the LCI approach was applied while the LCA software KCL-ECO was used for estimation of the energy and resources consumed. Slapnik et al. (2015) investigated the life cycle inventory or characterization factors or combination of both as well as the factors which affect the normalization results.

3.3. Reconfiguration of manufacturing systems

Reconfiguration is an effective way of redesigning the components of a system to ensure efficiency, modularity, scalability and flexibility (Koren et al., 1999). Fourie and Tendayi (2016) delve into the possibility of developing and implementing a reconfigurable life cycle framework in the railway industry. Sibanda et al. (2019) looked at the engineering design of the reconfigurable machine tool holistically. The study considered the development of a carbon efficiency framework in order to have a comprehensive view of low carbon manufacturing and characterize the life-cycle carbon emissions of machine tools. This is necessary in order to mitigate the challenge of high carbon manufacturing. The methodology was designed to minimize the environmental impacts of product from the design phase through the entire life cycle of the product. The approach focusses on the design process phase of a product to the development of prototype, and subsequently the manufacturing phase as well as the, packaging, distribution, assembly, use and end of life. Sibanda et al. (2019) also explained that it is necessary to design the product that are environmentally friendly throughout in their life cycles, which is sustainable and would enhance performance improvement. In conclusion, it was found that the DFM approach simplifies parts design parts for easy manufacture, reduce turnaround time, reduce production costs and reduce activities for redesign. DFA has a potential to reduce the number of component parts and consists of a lean assembly process which is cost effective. It integrates tooling and assembly methods in order to produce a quality reliable product. CE reduces the activities of the design process by making sure that the process runs concurrently, it also reduces time by overlapping activities. RMS includes grouped technology integrated machine, while ECD focuses on the life cycle of the product life. The proposed approach encourages the production of quality products and at an optimum costs while ensuring the efficient use of resources without any compromise to the natural environment.

Daniyan et al. (2019a) developed a reconfigurable fixture for low weight machining operations. The reconfigurable fixture was designed to use pneumatic controllers. The design was carried out with the aid of Autodesk Inventor and simulation of the developed fixture was done using FESTO fluid SIM to test the performance of the designed circuit and pneumatic cylinders. Seloane et al. (2020) presented a conceptual design of intelligent reconfigurable welding fixture for the railcar manufacturing industry. The reconfiguration is aimed at solving the challenges encountered with the use of dedicated fixtures in the railcar manufacturing industries, so as to increase productivity, reduce cost and meet important deadlines. The Computer Aided Design (CAD) involving the use of Unigraphics was employed in the study for the design while the weight design matrix concept evaluation criteria was used for the selection of the most appropriate concept. The functional requirements were based on five features namely; intelligence, assembly, reconfigurability, manufacturability and maintainability.

Zhang et al. (2016) proposed an innovative reconfigurable assembly jig known as the Agile Joint Jig (AJJ). The jig consist of three major parts namely: the locators, framework as well as the auxiliary components. The parts are embedded with modules that can be reused to speedily configure other jigs for the development of new products. This is aimed at reducing the manufacturing cycle and effective jig repositioning for precision and accuracy during manufacturing operations.

3.4. Internet of things (IoTs) and web-based applications

Krautzera et al. (2015) investigated the use of IoT and other web-based applications in manufacturing. The validated was done in two steps: the preliminary assessment aimed at providing a rapid and general representative of the environmental impact profile which is suitable for the determination of the troubled spots. The second is the detailed assessment of the identified hotspots aimed at providing a comprehensive results of the nature of the troubled spots. This paves way for the development of improvement measures thereby increasing the awareness level.

Roberts and Goodall (2009) describes the railway rolling stock maintenance strategy as performed on a distance basis. The authors further described the use of a rolling stock borne equipment for the monitoring of the functionality of other rolling stock subsystems. The authors further explain how mandatory it is for trains to have On-Train Maintenance Recorder (OTMR). The OTMR's are used for event logging of data recording of any dysfunctionality relating to the rolling stock equipment. Zheng et al. (2008) proposed the use of the internet for technical communications through a planning module connected to the server. The machining process parameter web-based selection system was employed for agile turning to provide a platform for design and manufacturing as well as technical support system among different business partners in various geographical locations. Srinivasan et al. (2014) conducted a comparative analysis of the life cycle-based tools for the assessment of a structural infrastructure in terms of its energy consumption. The EIO-LCA, Eco-LCA, ATHENA® Impact Estimator, and emergy life cycle based tools were employed in the study. The EIO-LCA and ATHENA® Impact Estimator demonstrated the capacity for the LCA while Eco-LCA and emergy, provided decisions relating to sustainability. The sustainability measurement ranges from the design phase to the construction, phase as well as the operation and decommissioning phases of the building. The Eco-LCA and emergy evaluation, also captured the information relating to the impact of the manufacturing activities on the ecosystem services which were not captured not captured by the conventional LCA tools. Chen et al. (2018) proposed an energy effectiveness monitoring system for machining workshop with the support of the newly emerging Internet of Things (IoT) technology.

3.5. Computer aided process planning and cloud platforms

Afsharizand et al. (2014) have launched a new approach for the Computer Aided Process Planning (CAPP) system for the development of manufacturing capabilities aimed at dealing with outdated CNC machines and process performances. The depletion of manufacturing resources can trigger the development of parts that exceed the tolerance limits. This could affect the integrity and cost effectiveness the manufacturing process, thus, bringing about expensive rework as well as reduction in the energy and environmental sustainability. Hence, the identification of the factors which influence the degradation of machining resources degradation and compensating for such factors is critical in minimizing waste generation, as well as energy efficiency and production time improvement. The proposed framework which can adequately capture the machine tool's capacity has been integrated with machine tool specification model. The validation of proposed framework was carried out with on a 3 axis milling machine. The Mirantis Cloud Platform (MCP) presented in the study can be integrated within a machine capability interpreter in order to further explore the strength of this approach. Murena et al. (2018) developed a web-based process planning system with the aid of the Weighted Decision Matrix and Analytical Hierarchy Process. The validation of the developed system was carried out using a case study of sheet metal bending operations.

3.6. Software tool

According to de Souza Zanuto et al. (2019) the amount of energy consumed is a commonly used parameter in the optimization of the industrial machining processes in order to reduce the environmental impacts. There is a direct relationship between the amount of energy consumed during operation and the amount of carbon emitted. The mostly used methodology around the world to analyse the environmental impacts of product is the LCA (de Souza Zanuto et al. 2019). The LCA approach was applied in order to determine the environmental impacts of a single milling operation. The study is aimed at the identification of the process hotspots so that effort can be geared towards carbon emission reduction in order to promote environmental sustainability. The LCA tools chosen includes GaBi 6 software tool in combination with the SimaPro, while the impact assessment was based on the CML2001. A spider chart was used to show the impacted area by using multiples impact categories, and an average impact indicator.

3.7. Life cycle oriented services

According to Mert et al. (2014), resource efficiency has become an important requirement which the machine tools industry has to deal with. Various technical measures has been implemented by the machine tool manufacturers in order to improve resource efficiency of machine tools. Mert et al. (2014) developed a framework for improving the resource efficiency of a machine tool via a life cycle oriented services. The framework consolidates the existing technical measures aimed at improving the resource efficiency of a machine tool. The first step is that life cycle of a machine tool needs to be analysed from the customer perspective while the second step involves the assessment of resource efficiency and as well as the resources employed during the life cycle of a machine tool. The third step involves the identification of the services which have the potential to improve the resource efficiency of a machine tool while fourth step evaluates the impact on the resource efficiency. The resource used are matched with the defined services.

3.8. Life cycle costing and profit approach

Bengtsson and Kurdve (2016), conducted a study on Life Cycle Profit (LCP) and the application of the Life Cycle Costing (LCC) to machines tools. The study was conducted to assist in decision making the need to procure a new machine or maintain the existing ones at a high cost and at risk. The authors used the combination of literature survey and empirical research to conduct analysis of the LCP of the machine tool. The authors explained that it is very important to apply LCC approach at an early stage of an equipment to help in decision making. The case study of the study includes the dynamic energy, fluid and maintenance cost. Denkena et al. (2006) proposed the development of an LCC navigator for analysis. This is due to the fact that the decision for the procurement of production equipment that will guarantee life-cycle-costs (LCC) is gaining increasing attention. The price of machine tools is crucial for making investment decision. The optimum cost of procurement is the one that will ensure effective performance of the machine tool without sacrificing quality and performance. Enparantza et al. (2006) presents a program for the estimation of life cycle cost and management of machine tools. This is to enable the prediction of the life cycle cost.

3.9. Preventive structuring approach

Schmida et al. (2016) established a preventive structuring approach which is based on the product's design, and conceptualization for Multi-Technology Machine Tool (MTMT) effective management. For future consider, designers can weigh the possibility of accounting for the effects caused by the combination of different technologies on the processing accuracy during the early design stage. Furthermore, the determination of the standard interfaces and more product design to be integrated based on the manufacturing technologies can also be investigated.

3.10. Tool and equipment management approach

Heeschen et al. (2015) introduced a model for life cycle oriented milling tool management in small and medium scale productions. The study was supported by an industrial project which cuts across 13 manufacturing companies from Germany. The study presents an approach for the life cycle management of machine tool. Li and Chen (2014) as well as Zhang et al. (2012) also proposed suitable frameworks for tool and machining process monitoring as well as too wear detection based on machine vision in end milling process.

3.11. Technical product service system (t-PSS)

Azarenko (2009) developed a technical product service system (t-PSS) for supporting the BoX ultra-precision free-form grinding machine while Russell (2014) developed a framework to assist project managers in the procurement of a new machine tool. A detailed and correct planning for procuring and installation of a new machine tool is crucial. As this saves time and money for a project which affects the performance and useful life of a machine tool. Machine tools are a core part of manufacturing systems, they are vital for several purposes during; development of new and existing systems, usage and to end of life. Standard ISO 10303 (STEP) offers machines with a descriptive capability of the product data during the product's useful life (Kjellberg elal., 2009). A life cycle cost navigator (software tool) is being established in Germany; this software tool can offer technical support and assist in optimizing the selection of mechanisms (Denkena et al., 2006). Different maintenance divisions spend about 70% of total labour hours on preventive maintenance in order to safeguard reliability and long life of computerized numerical control (CNC) and other precision machine tools (Westerkamp, 2013). Organizations should utilise a team maintenance approach as so to improve reliability, reduce costs and increase machine tools' life cycle (Merkisz-Guranowska et al., 2014; Lee and Suh 2008). According to Lee and Suh (2008), the data on the machines upon delivery to the purchaser becomes unclear or unrecognized. Moreover, numerous real time data from the shop floor and usage data from the customers are not collected in real time. As a result, Lee and Suh (2008) developed a ubiquitous product life cycle support (UPLS) system based on the UbiDM. The system supports has the capability to provide feedback about the actual data usage relating to the product as well as the environment in which the product is being utilized. Chen and Huang (2019) applied the LCA approach with the integration of Product Service System (PSS). The authors stated that the huge environmental pressure caused by the presence of manufacturing industries promotes the setup of the recycling industries. It is crucial for the recycling industries to sustain the use of resources, with reduction in the magnitude of pollution in order to promote environmental friendliness and protection.

3.12. Real time monitoring approach

The word sustainability is not well understood in operations applied to different industries. A study conducted by Azkarate et al. (2011) proposed specific tools and means to empower sustainable design of future machine tools, which will enhance sustainable manufacturing. Machine failure can shorten the remaining useful life of components and affect products' quality, the initial step is to achieve more effectiveness, which can be achieved by the incorporation of sensors for monitoring of machine availability and quality of machining processes (Emec et al., 2016). The incorporation of smart sensors in machine tools is the building block for the internet of things (IoTs) and data analytics in manufacturing which aids the collection of data in real time for process improvement and optimum performance. A fault monitoring framework was developed by Emec et al. (2016) for machine tools grounded on data stream mining techniques for online pattern matching in electrical power data streams. According to Relea et al. (2019) non-stop exposure of oil or water based cutting fluids on granite machine tool beds could result in geometrical and dimensional variations in the machine's structure over a certain period. It can be concluded that humidity variations and fluid exposure for a long time can negatively negative impact the useful life of a machine tools.

3.13. Green cutting technology

The selection of the right cutting fluids and its right application are critical factors in enhancing the machine tool life and sustainability (Fallböhmer et al., 2000; Liao et al., 2008; Abele and Fröhlich, 2008; Fang and Wu, 2009; Chukwuma 2013; Garg et al., 2018). This is because manufacturing sustainability decreases with increase in the energy requirement of the process which is a function of the operating or cutting temperature. The cutting temperature is significant for the creation of a compressed region within the shearing zone and to enhance plastic deformation which promotes shearing and cutting action. However, the process sustainability reduces when the temperature exceeds the optimum. One way to keep the temperature within the optimum range is through temperature monitoring in real time via the use of infrared video thermometer or other suitable temperature measuring and monitoring devices (Daniyan et al., 2020a). In addition, the use of cutting fluids at the shear zone will reduce the coefficient of friction among the chips, tools and work piece interface (Okafor and Aramalla, 2006. Hadi et al., 2013; Sharma et al., 2016; Sidik et al., 2017). Furthermore, the use of nano-fluids been widely reported in reducing the cutting temperature, heat and friction. Hegab et al. (2015) employed nanofluid during the machining operation of Inconel 718, and significant cooling action was obtained when compared to the MQL. The efficiency of the cutting fluid is measured by its capacity for effective chip removal, heat dissipation, prevention of built up edges, reduction in tool wear, and reduction of temperature and friction at the interfaces of the cutting tool, work piece and chips generated. Cryogenics is the cooling technology that has continued to gain widespread application which involves the use of lubricating fluid such as liquid nitrogen (Mert et al., 2014; Bengtsson and Kurdve, 2016; Denkena et al., 2006; Enparantza et al., 2006), CO_2 (Schmida et al., 2016; Heeschen et al., 2015; Li and Chen, 2014), soluble oil based emulsion (Zhang et al., 2012; Azarenko, 2009; Russell, 2014) MQL-nanofluid (Kjellberg et al., 2009), the hybrid MQL cooling (Westerkamp, 2013) amongst others. Campitelli et al. (2019) explained that is important to achieve developmental sustainability in order to enhance the efficiency of resources in the manufacturing industry. The authors also state that the main types of machining include: drilling, turning, milling and grinding. During these stages of machining, an efficient approach needs to be considered. Currently the machine tool industry depends on Flood Lubrication (FL) techniques and Minimum Quantity Lubrication (MQL) which are used to minimize the effects of temperature and forces during machining. Kishawy et al. (2019) carried out the sustainability assessment of turning Ti–6Al–4V under different cooling conditions of the MQL and MQL-nanofluid while estimating the surface finish, power consumption and rate of tool wear. The work employs an algorithm for the evaluation of the degree of sustainability during the machining operation of Ti–6Al–4V alloy. The assessment of the cutting process involves the use of an integrated model which combines the machining performance and sustainability indicators.

3.14. Remanufacturing approach

Zhao and Ming (2019) conducted a study to optimize motor remanufacturing technology and improve material utilization. These optimization schemes can improve the eco-friendliness of motor manufacturing, and the consumption of non-renewable resources, and enable the growth of motor manufacturing to be integrated, which in return improves the sustainable production capabilities of the motor-powered system (Zhao and Ming, 2019). Creep life is the time taken for failure to arise due to a progressive increase in strain under stress at raised temperature. Like other aging processes, under standard conditions, there are three stages in creep life (Chatopadhyay, 2014). The lifespan of an engineered component is equal to the period or number of cycles required for an existing flaw to grow to critical size under the total stress, consisting of applied and residual stresses. Surface engineering can significantly enhance the life cycle of machine tools, it can enhance a very short lifespan of an uncoated tool to 33 times by merely coating it (Chatopadhyay, 2014). Manufacturing is a complex process with many different interactions between the parameters controlling the manufacturing machine tools (Avram et al., 2013).

3.15. Modelling approach

Silva et al. (2015) conducted a study on the use of a modelling technique which combines the Life Cycle Assessment (LCA) and the Design of Experiments (DoE) techniques for the investigation of a cylindrical plunge grinding for a 21-2N steel while Linke (2014) conducted a study on the various grinding tool life stages.

3.16. Multi-criteria decision approach

According to Sihag and Sangwan (2019), the machining process contributes to high environmental emissions. There is no universal guide or process to assess the maintainable performance of a machine tool considering the differences in the economic, environmental and social perspectives. Key indicators were used as an approach, which includes: economic indicators, environmental indicators and social indicators (Sihag and Sangwan, 2019). Daniyan et al. (2020c) employed the Analytical Hierarchy Process (AHP) technique for the selection of appropriate material as well as assembly method during the development of a railcar. The authors state that the need for improvement in the performance of railcar without compromise to sustainability in terms of materials, environment and process informed the use of a decision model for materials and assembly method selection. The selection process also takes into account the recovery process of material after its end of life. The challenge of selecting the appropriate materials and assembly method amidst emerging and existing materials with the conflicting attributes of the assembly methods represent a Multi-Criteria Decision (MCD) which necessitates the use of a decision model.

3.17. Optimization approach

The product markets is dynamic in nature and the quest for cost effectiveness, cutting edge technology profitability and improved performance to meet customers' demand are some of the challenges of organisations (Sihag and Sangwan, 2019). In order to encourage inter-organisation relationships the innovation process which encompasses the learning, growth and improvement processes must be clearly mapped out and recognized. In the context of the cutting tool industry, a database, which contains the relevant information about the tool life cycle of each cutting tools will aid the learning process. A generic database which combines the information and data for a wide range of machine tools with different histories will aid the analysis or assessment processes. This approach is believed to signify a continuous approach for the definition and identification of the machine or cutting tool history which can support the decision-making during the usage, maintenance, end of life or lifecycle assessment phases. According to Triebe et al. (2019), it is important to achieve energy efficient of machine tools to sustain manufacturing. The movements of the machine tool elements contributes to large amount of energy consumption. The purpose of the work was to optimize the weight of the machine tool using the multi-objective optimization approach especially during the use phase. The authors envisaged that the relationship between the weight reduction and the energy consumption is directly proportional, hence, significant weight reduction could bring about improvement in the energy conservation. The multi-objective optimization method was also used to show tradeoffs between various objectives. Tradeoffs are forecast with a Pareto front. The optimization approach was employed for the determination of the thickness of the materials employed for the machine tool development in order to reduce the weight without sacrificing the integrity of the machine tool under the required service conditions.

4. Results and discussion

The intention of all the authors in the articles reviewed was either to reduce the carbon emission, energy consumption, resources conservation and waste management, safety and health issues of operators' environmental protection or costing savings.

4.1. Discussion of findings on LCA principles for low carbon manufacturing

The study of Cao et al. (2012) indicates that the carbon efficiency approach will assist in gaining a good understanding of the life cycle carbon emissions and to characterize carbon emissions of machine tools. The findings of the study show that the energy consumption during the use and control phases accounts for about 90% of the carbon emissions. This however can be reduced by ensuring significant reduction in the weight of the machine tools up to about 80% via remanufacturing or recycling or other suitable end of life options (Cao et al., 2012). In order to duly reflect the current practice in the UK road construction, Huang et al. (2009) recommended a suitable LCA model should incorporate the maintenance and recycling scenarios, with the use of data that is specific to the UK road industry. Furthermore, a practical model should also represent as many as possible variables in a pavement project, must be populated with good quality data which must be tested and calibrated through real case studies.

Du et al. (2015) emphasized that the low-carbon manufacturing model is a strategy to optimize the resource and energy consumption so as to reduce the amount of carbon emitted significantly. In order to address the challenges of low carbon manufacturing, the overall manufacturing model consists of the following layers: objective, strategy, life cycle layer and supporting layers, from the product's life cycle perspectives. In addition, in order to achieve low-carbon manufacturing, there is a need for product redesign, effective process and source control, as well as End of Life (EoL) product recovery. The study proposed suitable low-carbon models for the machinery manufacturing industry.

Burchart-Korol et al. (2016) suggested the need for significant reduction in the amount of steel material during manufacturing in order to reduce the amount of energy consumed so that the manufacturing process can be more sustainable and environmentally friendly. There is a direct link between the weight of a material and the energy consumption and as such there is increasing demand for lightweight materials which can meet the structural and operational requirements as substitutes for the existing materials. Kim and Wallington (2013) explains that the replacement of conventional materials such as iron and steel with lighter materials such as aluminum or composites can result in a decrease in the energy consumption and greenhouse gas (GHG) emissions during the use phase but with an increase in the energy consumption and GHG emissions during production phase. Hence, the use of lightweight materials is a viable option in order to reduce life cycle energy demand and GHG emissions. This however depends on the material source, process type and inventory data source of the lightweight materials Kim and Wallington (2013).

Grinding is normally the ultimate step in the manufacturing chain by means of an abrasive tool, the abrasive tool can wear, but a vital feature of all grinding machines is the dressing device used to regenerate the abrasive tool geometry and cutting ability (Wegener et al., 2017). Cubic boron nitride (CBN) grains are largely applied for super coarse materials in the manufacturing of high precision grinding wheels. In spite of technological results and the financial value, the involvement of carbon boron nitride (CBN) grinding wheels to the general eco-friendly impact has not been fully investigated and understood (Winter et al., 2015), hence, the life cycle assessment approach is a method that can be used to calculate the general eco-friendly impact.

The findings from the study of Diaz et al. (2010) on LCA of two types of machine tools (Bridgeport Manual Mill Series I and Mori Seiki DuraVertical 5060) with low and high automation levels respectively indicate that both machines required significant energy for operation during product's manufacturing. The material extraction phase was found to be the most energy-intensive phase which accounts for approximately 70% of the total energy consumed during the process of manufacturing, followed by the material casting phase. The more the energy requirement of a manufacturing phase, the more the energy related costs and the environmental impact (Herrmann et al., 2009). In conclusion, Herrmann et al. (2009) states that the extended analysis of energy consumption of machine tools in the study indicates a need for a comprehensive consideration of energy dynamics of process parameters, components and energy transformation in order to optimize the energy consumed during the machining processes. According to Di Orio et al. (2013) there is a growing number of demands to reduce the environmental impact during the manufacturing cycle. The manufacturing industries are encouraged to adopt green technologies to improve the energy efficiency of the manufacturing lines. In order to achieve this, the authors proposed the use of the Self-Learning Production Systems (SLPS) which strikes the right balance among the availability, effective resource utilization and efficiency of the production systems with the capacity for the overall system's performance and improvement. Machine tools consumes large amount of energy during the usage stage of the life cycle. The power consumption estimate during use phase will provide an insight into the development of a sustainable model for energy and costs optimization. The authors proposed a simulation based approach method for the determination of the energy consumed during the usage phase of life. The efficiency of the machine tools can be improved in two ways: reduction of friction and losses relating to damping, eclectic, hydraulic and pneumatic losses as well as optimization of the main energy put into the manufacturing activities (Daniyan et al., 2019b, 2019c).

4.2. Discussion of findings on life cycle inventory and impact assessment

Zendoia et al. (2014) established that to improve the processes of LCA, the inventory phase of the machine tools has to be well defined. Furthermore, the process of data collection is another critical stage in every life cycle assessment (LCA) in which the collected data has to be properly defined in their different usage modes most especially for machine tools. The results obtained from the novel approach for LCA application, indicate an overall improvement in environmental sustainability. The findings also provides a good indication and baseline for the improvement of the LCA for machine tools. The novel LCA method can be used to assess the resources and the environmental impact of products, throughout their life cycles which forms a major part of the eco-efficiency implementation. The authors state that the Life Cycle Inventory method for the performance evaluation of machine tools should be conducted for proper assessment of the environmental implications relating to the manufacturing processes and its sub-systems. The authors highlighted the three major phases which characterize the LCA methodology of a machine tool. These are:

- ❖ Life Cycle Inventory (LCI) - electrical energy and materials or substances used.
- ❖ Life Cycle Impact Assessment (LCIA) – This addresses the environmental impact of the energy consumed and resources employed during the manufacturing operation.
- ❖ Analysis and the interpretation of results.

According to Zendoia et al. (2014) during the manufacturing phase the machine tools industry makes a huge contribution or impact on global warming.

It was found that in the household manufacturing, less energy is required during the production after the calculations. The machining processes applicable to the aeronautic sector were investigated and it was also found that the processes were energy intensive. Slapnik et al. (2015) established that there are some uncertainties which characterized the LCA results. These can be traced to life cycle inventory or characterization factors or combination of both. The authors suggested that the researches involving LCA should look beyond the damage-oriented assessment. This is due to the fact that the costs for remediating the damage may not be insufficient from a practical perspective. However, from a holistic point of view, the provision of energy for remediation will impact the environment negatively thereby promoting circulation between environment degradation and restoration. Grünebaum et al. (2019) explained that companies around the globe are confronted with a shortage of critical raw materials. It is essential that these resources are used as efficiently as possible Dilip Jerold & Pradeep Kumar (2012). The approach is that companies need to use a model to optimize tool characteristics and process parameters. In conclusion, the author proposed the information accuracy and comprehensiveness as the metrics for the quick assessment of the LCI Life. Therefore, using the metrics, tool manufacturers need to assess the feasibility of using an already existing unit process LCI to evaluate material and resource flows in processes. In conclusion, the defined approach could essentially support the manufacturers in the development of a more efficient machine tools, focusing on the environmental impact estimations. The study only focused on the manufacturing and using stages, it did not cover the whole recycle phase.

4.3. Discussion of findings on reconfiguration of manufacturing systems

Life cycle framework in railway environment where rolling stock has a limited life span was found to be an important aspect in supporting the Reconfigurable Assembly Manufacturing System (RAMS). According to Fourie and Tendayi (2016), it is essential to have a life cycle framework in the railway industry as Reconfigurable Assembly Manufacturing Systems (RAMS) has become the most significant part of decision taking in the railway manufacturing environment. The authors' further stresses that the effective maintenance management is the key foundation in ensuring that the life cycle management is achieved and this can improve the overall profitability of the industry. The authors also established that the best approach to product development is to integrate the elements of the Design for Manufacture (DFM), Cutting Edge (CE) technology, Design for Assembly (DFA), Reconfigurable Manufacturing System (RMS) and Electrochemical Deburring (ECD) for product development. DFM can provide a guide on the parts design for easy manufacturing with improved lead time and cost effectiveness, production cost. Similarly, with the DFA approach the number of parts can be significantly reduced in order to have a robust and lean assembly process. In other words, the design approach integrates all the necessary the tools and method of assembly for the production of a quality product (Fourie and Tendayi, 2016).

The results from the case study carried out by Sibanda et al. (2019) indicate that light weight design and the adoption of end of life options such as remanufacturing can significantly reduce the fixed emissions which relates to the development of the machine tool, while the varied emissions which is a product of the emissions generates during the routine operation of the machine tools can be varied by ensuring improvement in the energy consumption and efficiency while ensuring that the assigned production task matches the machines tool specifications (Li et al., 2017). According to Sibanda et al. (2019) the product life cycle that need to be assessed should include: the design, production, transportation, installation, usage or operation, maintenance and end of life. The authors explained that a product in a machine tools industry should be divided into modules for effective assessment of the different phases of the life cycle (Sibanda et al., 2019). The authors proposed the approach or methodology that involves comprehensive process that includes eco-design (ECD), DFM, CED, RMS, and DFA. Daniyan et al. (2019a) found out that the reconfigurable fixture developed was an improvement over the existing fixtures because it balances some ergonomic issues (comfort and operator's safety) precise and smart location in a cost effective manner. The only limitation was the restriction of its use to low weight operations (maximum of 15 kg). The reconfigured fixture finds application in manufacturing industries as a work holding device for low weight components during machining operations. The results of the Finite Element Analysis (FEA) indicate that the clamping force is adequate to withstand the operational forces without any deformation. Thus some special attraction to the reconfigured fixture include high flexibility, sustainability (in terms of energy consumption), satisfactory clamping rigidity and high strength. The results of the conceptual design of intelligent reconfigurable welding fixture for the railcar manufacturing industry presented by Seloane et al. (2020) indicate that the system is capable of achieving precise welding assembly with significant reduction in the scrap rate, improved flexibility and versatility which is necessary to meet the dynamic nature of market, improved quality of product parts, improved set up time and reduction in the production cost.

4.4. Discussion of findings on internet of things (IoTs) and web-based applications

Krautzera et al. (2015) submitted that with the use of IoTs and web based applications manufacturing activities can be enhanced. From the analysis of the findings obtained, the software demonstrate tendency for application to wide variety of different industrial machines and operations namely: electro-discharge and milling machines operations etc. The useful life of the machine tool could still be improved via the development of a database having inputs from across the various market. This concept requires a different approach from the data storage concept, which might raise security concerns. Roberts and Goodall (2009) identify the significance of the On-Train Maintenance Recorder (OTMR) for event logging of data recording of any dysfunctionality relating to the rolling stock equipment. Hence, the use of automatic detectors have been found to be beneficial and as such should be integrated into the train system during the development stages (Roberts and Goodall, 2009). Zheng et al. (2008) explain that the use of the internet for technical communications via a process parameter planning module on the server will enable the users to choose the appropriate machine and cutting tools, as well as machining parameters for the machining operations. Furthermore, it also offers a platform for evaluating the performance of the machining operation in terms of the machining force, energy consumption, vibration and work piece distortion. Therefore, this system can greatly minimize the life cycle cost of a product and enhance the product's quality, with reduction in the manufacturing lead-time. The findings from the study of Srinivasan et al. (2014) show that each of the life cycle based tools have their strength and weakness, hence, the combination of some of the tools will compensate for the weaknesses identified. Based on the finding of the study, the development of data inputs as well as results analysis and interpretation especially for mainstream applications, is key, necessary efforts must geared towards the tracking of data at all the stages of the product's life cycle including the End-of-Life (EoL) stage. Chen et al. (2018) submitted that manufactures can reduce the energy consumption, energy cost and increase life span of machine tools by utilising the IoT and other web based applications.

4.5. Discussion of findings on computer aided process planning and cloud platforms

The novel Mirantis Cloud Platform (MCP) launched by Afsharizand et al. (2014) has been integrated with machine tool specification model. It has the capacity to adequately capture the machine tool's capacity and

Table 2. Summary of findings.

Topics	Author	Focus	Approach
Carbon Efficiency	Cao et al. (2012)	Carbon efficiency indicators of machine tools	LCA principles
	Sibanda et al. (2019)	Characterization of the life-cycle carbon emissions of machine tools	Reconfiguration
	Du et al. (2015)	Novel approach to improve energy efficiency and reduce carbon emission.	The authors has established a system framework of low-carbon operation models for machinery manufacturing industry as a model to investigate the situation.
Life cycle assessment and Inventory	Zendoia et al. (2014)	Established the need to clearly define the inventory phase of the machine tools for improved clarity and consistency of the entire life cycle	Life cycle inventory and impact assessment
	Heijungs et al. (1992)	Life cycle assessment of products	Exploratory
	Chen and Huang (2019)	Application review of LCA (Life Cycle Assessment) in circular economy	Exploratory
	Zheng et al. (2008)	life cycle cost reduction	A web-based
	Huang et al. (2009)	Development of a LCA model for construction and maintenance of asphalt pavements for improved process sustainability	Used the concept of Life Cycle Assessment for model development
	de Souza Zanuto et al. (2019)	Development of a decision making framework for assessing the resources consumed and their environmental impacts during machining operation	Life cycle assessment software tool.
	Grünebaum et al. (2019)	Life cycle phases	Exploratory
	Fourie and Tendayi (2016)	A decision-making framework for effective maintenance management	Life cycle costing
	Slapnik et al. (2015)	To extend the life cycle assessment normalization factors	Machine learning approach technique
	Krautzera et al. (2015)	Application of the webtool	Internet of Things (IoTs) and web-based applications
	Jiang et al. (2012)	Environmental performance assessment	Exploratory
	Mert et al. (2014)	Development a framework for improving the efficiency of resources during manufacturing operations	Life cycle oriented services
	Matthews et al. (2014)	Life cycle assessment	Exploratory
Life cycle assessment and Inventory	Schmida et al. (2016)	Life Cycle of Multi Technology Machine Tools – Modularization and Integral Design	Preventive structuring methodology
	Heeschen et al. (2015)	Life cycle oriented tool management during machining operation	Tool and equipment management technique
	Diaz et al. (2010)	Environmental sustainability	LCA and redesign
	Lee et al. (2012)	Sustainability of Manufacturing System	Simulation-Based Analysis
	Huang et al. (2009)	Development of a life cycle assessment tool	Case study
	Burchart-Korol et al. (2016)	Environmental life cycle assessment	Case study
	Winter et al. (2015)	Life cycle assessment	Exploratory
	Li et al. (2017)	carbon efficiency of cutting tools	A life cycle approach
Energy Efficiency	Srinivasan et al. (2014)	Energy efficiency	Use of life cycle-based tools for energy consumption in a building
	Garg et al. (2018)	Power consumption minimization	Modelling
	Tůma et al. (2014)	Energy consumption in machine tools	Empirical
	Afsharizand et al. (2014)	Comparison of Energy, cost and environmental sustainability using energy-based indicators used in life cycle assessment tools for buildings	Use of Computer Aided Process Planning (CAPP)
		Resource and energy consumption	Development of operational models for energy efficiency improvement and environmental sustainability
	Chen et al. (2018)	Energy effectiveness monitoring system for machining workshop with the support of the newly emerging Internet of Things (IoT) technology	Real time monitoring approach
	Triebe et al. (2019)	Energy efficiency for sustainable manufacturing.	Multi-objective optimization
	Silva et al. (2015)	Improvement in the process and energy consumption	Use of a modelling method that combines the Life Cycle Assessment (LCA) and the Design of Experiments (DoE) to study a cylindrical plunge grinding for a 21-2N steel.
	Campitelli et al. (2019)	Improvement in energy consumption	Green cutting technology.

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Table 2 (*continued*)

Topics	Author	Focus	Approach
	Duflou et al. (2012)	Towards energy and resource efficient manufacturing	Processes and systems approach.
	Priarone (2016)	Energy optimization	Application of sustainability indicator
Energy Efficiency	Du et al. (2015)	Novel approach to improve energy efficiency and reduce carbon emission.	The authors has established a system framework of low-carbon operation models for machinery manufacturing industry as a model to investigate the situation.
	Herrmann et al. (2009)	Energy efficiency of machine tools:	Exploratory
	Di Orio et al. (2013)	Energy efficiency in machine tools	Self-learning approach
Machine Tool	Azarenko (2009)	Combination of cutting-edge mass production and ultra-precision technologies.	Technical product service system (t-PSS)
	Hegab et al. (2015)	Electrical Discharge Machining	Statistical design, modelling and optimization
	Kjellberg et al. (2009)	The machine tool model	Exploratory
	Bengtsson and Kurdve (2016)	Machining equipment life cycle costing model	Modelling
	Westerkamp (2013)	Optimization of machine tool	
	Denkena et al. (2006)	Optimization of machine design	Proposed the development of an LCC navigator for analysis
	Lee and Suh (2008)	Machine tools with product data model	Modelling
	Emec et al. (2016)	Use of diagnostic and prognostic online tool for fault monitoring and improved resource-efficiency	Real time monitoring approach
	Zhao and Ming (2019)	Optimization of a remanufacturing technology for motors with improvement in material sustainability.	Remanufacturing approach
	Sihag and Sangwan (2019)	Quantification of the maintainable performance of a machine tool	Multi-criteria decision approach (AHP)
	Gao and Wang (2017)	Machine tools: From design to remanufacture.	Through life analysis
	Diaz et al. (2010)	Machine tools	Exploratory
	Daniyan et al. (2019c)	Machine tools	Empirical
	Azkarate et al. (2011)	Sustainable machine tools	Exploratory
	Krautzera et al. (2015)	Environmental performance of machine tools	Case studies applying the 'LCA
	Zhang et al. (2012)	Machine tool	Empirical
	Chatopadhyay (2014)	Tool life-cycle	Exploratory
	Linke (2014)	Life cycle of grinding tools	Exploratory
	Avram et al. (2013)	Life cycle costs of machine tools	Exploratory
	Brenner et al. (2017)	Life cycle management of cutting tools	Exploratory
Circular Economy	Geissdoerfer et al. (2017)	The Circular Economy	Novel sustainability paradigm
	Jawahir and Bradley (2016)	Technological elements of circular economy	Exploratory Approach
	Murray et al. (2017)	The circular economy:	An interdisciplinary exploration of the concept and application in a global context
	Wu et al. (2014)	Effectiveness of the policy of circular economy	DEA-based analysis
	Duflou (2008)	Efficiency and feasibility of product disassembly	A case-based study
	Phuluwa et al. (2019)	End-of- life components reusability.	Exploratory approach
Machining operations	Shokrani et al. (2012)	CNC Milling	Empirical
	Dilip Jerold & Pradeep Kumar (2013)	CNC Milling	Empirical
	Bĭcek et al. (2012)	CNC Turning	Empirical
	Courbon et al. (2013)	CNC machining	Empirical
	Tapoglou et al. (2017)	CNC machining	Empirical
	Dilip Jerold & Pradeep Kumar (2012)	CNC Turning	Empirical
	Fernández et al. (2019)	Cryogenic milling	Empirical
	Pereira et al. (2016)	CNC Milling	Empirical
	Pereira et al. (2017)	CNC Milling	Empirical
	Cordes et al. (2014)	Cryogenic cooling	Empirical
	Kaynak et al. (2014)	Cryogenic milling	Empirical
	Feyzi and Safavi (2013)	CNC machining	Empirical
	Campitelli et al. (2019)	Resource efficiency analysis of lubricating strategies	Machining processes using life cycle assessment
	Kishawy et al. (2019)	Machining of titanium alloy	Empirical
	Pusavec et al. (2010)	Application on machining technologies	Exploratory

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Table 2 (*continued*)

Topics	Author	Focus	Approach
	Daniyan et al. (2019c)	CNC Milling	Empirical
	Tlhabadira et al. (2019)	CNC Milling	Empirical
	Daniyan et al. (2020a)	CNC Milling	Empirical

Table 3. Summary and contributions.

Author	Focus	Approach	Findings and contributions
Cao et al. (2012)	Carbon efficiency indicators of machine tools as the production rate carbon efficiency, material removal rate carbon efficiency and economic return rate.	LCA principles	Carbon emissions were traced to by high energy consumption during use and control the life cycle which add up to approximately 90%. Significant reduction approximately 80% in weight reduction of the machine tools via the EoL options. Some of the EoL options include: reuse, reconditioning, refurbishment, repair, remanufacturing, and recycling. The framework for the EoL option is illustrated in Figure 3
Zendoia et al. (2014)	Established the need to clearly define the inventory phase of the machine tools for improved clarity and consistency of the entire life cycle	Life cycle inventory and impact assessment	Life Cycle Inventory (LCI) - electrical energy and materials or substances used.
Sibanda et al. (2019)	Characterization of the life-cycle carbon emissions of machine tools	Reconfiguration	The authors proposed the approach or methodology that involves comprehensive process that includes eco-design (ECD), design for manufacturing (DFM), CED, RMS, and design for assembly (DFA).
Krautzera et al. (2015)	Application of the webtool	Internet of Things (IoTs) and web-based applications	Framework for identification of hot and trouble spots during machine tool operation
Srinivasan et al. (2014)	Energy efficiency	Use of life cycle-based tools for energy consumption in a building	The life cycle of building from the design phase, construction, operation, to the decommissioning phase significantly affect the energy and environmental sustainability
Afsharizand et al. (2014)	Comparison of Energy, cost and environmental sustainability using energy-based indicators used in life cycle assessment tools for buildings	Use of Computer Aided Process Planning (CAPP)	The authors proposed a framework which captures the machine tool's capability and has been integrated with machine tool specification model introduced in ISO 14649-201 as well as the testing protocol of machine requirements defined in ISO 14649.
Yuang et al. (2009)	Development of a LCA model for construction and maintenance of asphalt pavements for improved process sustainability	Used the concept of Life Cycle Assessment for model development	The integration of maintenance and recycling into the LCA model
de Souza Zanuto et al. (2019)	Development of a decision making framework for assessing the resources consumed and their environmental impacts during machining operation	Life cycle assessment software tool.	Effective process planning can significantly reduce the impacts of machining operations on the environmental
Slapnik et al. (2015)	To extend the life cycle assessment normalization factors	Machine learning approach technique	The generation of energy for remediation impact the environment negatively.
Mert et al. (2014)	Development a framework for improving the efficiency of resources during manufacturing operations	Life cycle oriented services	Machine tool design and the delivery of efficient PSS is key to sustainability. Development of framework and its implementation.

(*continued on next page*)

Table 3 (*continued*)

Author	Focus	Approach	Findings and contributions
Schmida et al. (2016)	Life Cycle of Multi Technology Machine Tools – Modularization and Integral Design	Preventive structuring methodology	Establishment of preventive structuring based approach for effective Multi-Technology Machine Tool (MTMT) management
Heeschen et al. (2015)	Life cycle oriented tool management during machining operation	Tool and equipment management technique	Managing industrial equipment without the influence of the end users.
Azarenko (2009)	Combination of cutting-edge mass production and ultra-precision technologies.	Technical product service system (t-PSS)	Developed a technical product service system (t-PSS) for the BoX ultra-precision free-form grinding machine.
Denkena et al. (2006)	Optimization of machine design	Proposed the development of an LCC navigator for analysis	Life cycle costing model to assist the machine manufacturers in the optimization of design during the design phase of the machine development.
Emec et al. (2016)	Use of diagnostic and prognostic online tool for fault monitoring and improved resource-efficiency	Real time monitoring approach	Online fault-monitoring in machine tools critical to improvement in energy consumption and resource-efficiency.
Zhao and Ming (2019)	Optimization of a remanufacturing technology for motors with improvement in material sustainability.	Remanufacturing approach	These optimization schemes can improve the eco-friendliness.
Chen et al. (2018)	Energy effectiveness monitoring system for machining workshop with the support of the newly emerging Internet of Things (IoT) technology	Real time monitoring approach	Manufacturers can optimize the material consumption, energy cost and increase life span of machine tools by utilising the IoT
Sihag and Sangwan (2019)	Quantification of the maintainable performance of a machine tool	Multi-criteria decision approach (AHP)	Proposed guideline to provide decision support for to assess the level of sustainability and enhance sustainability performance.
Triebe et al. (2019)	Energy efficiency for sustainable manufacturing.	Multi-objective optimization	Framework for the reduction of the weight of a machine tool from the design phase.
Burchart-Korol et al. (2016)	To increase the environmental performance of coal mining processes, emissions of methane and consumption of electricity, heat and steel.	Computational LCA model for the estimation of the environmental LCA for a coal mining processes.	High energy consumption and emissions are linked to the use of steel, hence, materials with high strength to weight ratio are recommended.
Silva et al. (2015)	Improvement in the process and energy consumption	Use of a modelling method that combines the Life Cycle Assessment (LCA) and the Design of Experiments (DoE) to study a cylindrical plunge grinding for a 21-2N steel.	Authors recommends that a few machined work pieces be used as an LCA locus flow rather than time, for an improved monitoring of the grinding process
Campitelli et al. (2019)	Improvement in energy consumption	Green cutting technology.	Life cycle assessment on these two lubrication techniques (Flood Lubrication and Minimum Quantity Lubrication). The use of the FL technique has more impact to environment than MQL technique due to lubricating pump consuming higher energy when using FL technique when compared to MQL [46].
Du et al. (2015)	Novel approach is to improve energy efficiency and reduce carbon emission.	The authors has established a system framework of low-carbon operation models for machinery manufacturing industry as a model to investigate the situation.	Low-carbon manufacturing model aimed at solving the challenges of high energy consumption and carbon emission.
Diaz et al. (2010)	Environmental sustainability	LCA and redesign	Redesign of machine tool and review of operation strategies aimed at low carbon manufacturing

can be integrated within a machine capability interpreter in order to further explore the strength of this approach. Murena et al. (2018) found that the developed Computer-Based Process Planning (CBPP) system has the capacity to has the ability to transform sheet metal plates into net shape parts. The system boast of time effectiveness and production of optimal parts quality when compared to traditional systems. It also permits the data exchange via different sheet metal manufacturing industries.

4.6. Discussion of findings on software tool

Using the LCA approach to determine the environmental impacts of a single milling operation, de Souza Zanuto et al. (2019) found that the commercial LCA software tool applied demonstrated effectiveness in the assessment of the resources consumed and environmental impacts during the industrial milling process. It is envisaged that this will allow for effective allowing decision-making regarding the environmental impacts. The spider chart shows the areas which negatively impacted area were taking into consideration the multiples impact categories and the average impact indicator. The provision of a visual and numerical analysis, will allow effectively comparison of various strategies when compared to the multiple environmental impact categories with different units. The findings indicate that an average size mill generates more impact than a micro mill. Furthermore, it was revealed that operations at slow speeds impacts the environment more than the operations carried out at high speed (Heijungs et al., 1992).

4.7. Discussion of findings on life cycle oriented services

The framework for improving the resource efficiency of a machine tool via a life cycle oriented services developed by Mert et al. (2014) provides the machine tool manufacturers a platform to design and deliver on resource efficient Product Service System (PSS). This will promote significant contribution to sustainable manufacturing which has occupied the front burner in the manufacturing sphere in recent times. Future research can consider the validation of the proposed framework with industrial case studies especially from the machine tool industry. This will enable the quantitative LCA of the impact of the incorporated services on the efficiency of the machine tool.

4.8. Discussion of findings on life cycle costing and profit approach

In the study on Life Cycle Profit (LCP) and the application of the Life Cycle Costing (LCC) to machines tools conducted by Bengtsson and Kurdve (2016), the authors found that LCC aspects is suitable for making decision at the design phase on the nature of components to be purchased. The outcome would help in the aspect of equipment design suggestion with respect to easy maintenance, easy cleaning and easy operation. Bengtsson and Kurdve (2016) also reported that the LCC/TCO aspects of the machine tool can be used as a guidelines for the determination of the components to be considered during the design phase. At the purchasing phase, critical factors to be considered in addition to the functional requirements include: downtime costs, energy consumption, production rate and cost, maintenance and repair costs, as well as process fluids which changes with the equipment age. A good understanding of this factors will provide an insight into the implications on equipment design, maintainability, operation and sustainability. The stochastic parameters however may require additional cost, risk analysis or simulation in order for their proper capturing (Bengtsson and Kurdve, 2016). Denkena et al. (2006) found that the LCC navigator developed is suitable for LCC analysis. The results indicate that LCC navigator can assist manufacturers in the determination of the optimum cost and optimization of the machine design. The life cycle concepts are gradually considered by machine tools industry. The results of the program for the estimation of life cycle cost and management of machine tools presented by Enparantza et al. (2006) indicate that the proposed program proposed permits the estimation of the machine tool's life cycle and effective management of the machine RAM data. The analysis of grinding machine LCC indicates that 80% of the costs occur during the operation phase, and the results also revealed that five activities (concept and definition, design and development, manufacturing, assembly, installation) were the ones that generated more cost burden during the life cycle of the machine (Enparantza et al., 2006).

4.9. Discussion of findings on technical product service system (t-PSS)

The BoX machine developed by Azarenko (2009) is an innovative machine that can combine cutting-edge mass production and ultra-precision technologies. The t-PSS gathers and reuses information in a closed loop process to enhance the system. According to Gao and Wang (2017), environmental drain requires the transition from the traditional way of manufacturing to a more sustainable approach with emphasis on material recovery, reuse, and remanufacture. A machine tool's life cycle can be perceived as a cycle which commences from the design, and runs through the manufacturing, usage, and end of life phases whereby it is reclaimed into service thus forming a loop. It is more challenging and less profitable to strip and restore machine tools through end of life options such as remanufacturing, conversely to mere retrofitting (Gao and Wang, 2017). According to the results obtained by Chen and Huang (2019), following the integration of the LCA approach with the integration of Product Service System (PSS) indicate that the LCA method can only be used in decision-making process, or trade-offs. In order to ensure the accuracy, practicability and operability of the life cycle assessment should be timely adjusted to ensure that its purpose and scope aligns with the principles and framework of life cycle assessment and specific application intentions.

4.10. Discussion of findings on green cutting technology

Previous studies have shown that the use of fluid during the machining operation can significantly prolong the useful tool life when compared to dry cutting (Kamata and Obikawa, 2007; Dhar et al., 2007; Kaynak, 2014; Garg et al., 2018; Okafor & Jasra, 2018, 2019). Many researchers have also reported on the use of minimal quantity lubrication (MQL) involving the cooling action of a compressed air (Kamata and Obikawa, 2007; Kaynak, 2014; Sharma et al., 2016).

The limitation being that the cooling action of the compressed air is usually less efficient under high speed cutting operation as well as cutting operation involving materials with high heat retention capacity such as titanium due to its low thermal conductivity (Zhao et al., 2007; Daniyan et al., 2019d). Furthermore, the use of nano-fluids been widely reported in reducing the cutting temperature, heat and friction. Hegab et al. (2015) employed nanofluid during the machining operation of Inconel 718, and significant cooling action was obtained when compared to the MQL. The efficiency of the cutting fluid is measured by its capacity for effective chip removal, heat dissipation, prevention of built up edges, reduction in tool wear, and reduction of temperature and friction at the interfaces of the cutting tool, work piece and chips generated. Cryogenics is the cooling technology that has continued to gain widespread application which involves the use of lubricating fluid such as liquid nitrogen (Mert et al., 2014; Bengtsson and Kurdve, 2016; Denkena et al., 2006; Enparantza et al., 2006), CO_2 (Schmida et al., 2016; Heeschen et al., 2015; Li and Chen, 2014), soluble oil based emulsion (Zhang et al., 2012; Azarenko, 2009; Russell, 2014) MQL-nanofluid (Kjellberg et al., 2009), the hybrid MQL cooling (Westerkamp, 2013) amongst others.

4.11. Discussion of findings on remanufacturing

Gao and Wang (2017) reported that the concept of machine tool repair and retrofit are critical in order to improve the product's life cycle. Currently there are limited technologies which reflects difficulties and less cost effective to refurbish machine tools through remanufacturing.

The need for more advanced technologies is essential. More standards need to be developed to monitor the design and remanufacturing.

4.12. Discussion of findings on modelling

Silva et al. (2015) in the study a cylindrical plunge grinding for a 21-2N steel using the combination of LCA and DoE techniques recommend that a few machined work pieces be used as an LCA locus flow rather than time, for an improved monitoring of the grinding process. Linke (2014) explains that the most significant reasons for end of grinding tool life are tool wear to the minimum abrasive layer dimensions and tool degradation at the end of shelf life according to the study. Currently, abrasive tools are repeatedly disposed as wastes which lead to waste combustion or landfill with negative impacts on the environment (Linke, 2014). The study recommends a computer tool for assessing and measuring the effects of different manufacturing choices using selected measures. Further surface engineering as a solution to extend machine tool lifespan was also recommended. This is because, the principles of surface engineering increases the material's lifespan by minimizing the extent of degradation through tribological interactions and associated aging processes (Avram et al., 2013).

4.13. Discussion of findings on multi-criteria decision approach

Sihag and Sangwan (2019) found that there is still a challenge in sustaining the performance of machine tools. The Analytical Hierarchy Process (AHP) technique was applied to rank the identified indicators based on the assigned weights. The findings indicate that the machining parameters and the lubricating conditions are critical factors which enhances the performance of the machine tool. The cutting operation without the use of lubricating coolants (dry machining) was observed to conserve energy better than the cutting operation with the use of lubricants (wet machining). This implies that the energy requirement of the process increases with the use of the lubrication during the cooling process and vice versa. The disadvantage of dry machine is that machine tool life cycle shortens, the machining under effective lubrication performs better in terms of the products' dimensional accuracy and economic benefit. Therefore, it is envisaged that proposed guide can provide a scientific basis and decision support system to machine tools manufactures to assess the sustainability performance of the machine tools. Daniyan et al. (2020c) found that, the AHP technique is suitable for arranging the multi-criteria problem in a hierarchical order and ranking the criteria vis-à-vis the goals and available alternatives. The decision model framework involving the use of AHP provided the analysis of the materials and assembly methods that can meet the functional requirements of the railcar in a ranked order. Thus, the study demonstrates the application of decision support model for decision-making in the railcar manufacturing industries.

The common things of all the articles covered in this study are that most authors focused on: reduction of energy used during manufacturing and use, reduction of carbon emission, development of efficient product, the type of lubricating to be used and cutting fluids such as the compressed air and the impact caused by metalworking fluids. The use phase contributes to most of the total emissions which characterizes the life cycle of the machine tools. The amount of emissions generated at the manufacturing phase were significant most especially for facilities that are not energy efficient. There are different techniques employed by different organization in the machine tools industry. In this study the authors selected focused mostly on LCA and LCC as a method or technique. Life cycle includes different stages, starting from raw material acquisition or natural resources up to final stage which is disposal. Some of the articles studied had focused on different phases or stages to tackle in terms of environmental impact. The usage stage is the most focused stage because of the large energy consumption which is peculiar to the stage. Another stage is the initial stage to ensure that efficient resources are used. Due to the fact that some manufacturers are not using efficient resources, most of the machine tools industry do not meet the requirement of this technique. Most machine tools industry do apply life cycle but do not consider all stages/phases of the life cycle. In most of the articles reviewed, environmental management standards are not considered as a technique to improve the environmental impact.

Most of the articles reviewed included the life cycle in different techniques. It is very crucial to consider life cycle at every stage of the product during the manufacturing. This implies that every phase need to address the environmental impact and sustainability. LCA is one of the well-known techniques applied by most industries. ISO (2006) is a standard that was developed to manage environment by covering principles and techniques. LCA principle and techniques are very crucial for the successful implementation of environmental management strategies. Having established that the machine tool industry contribute significantly to carbon foot print and other sustainability challenges during the manufacturing phase, Pusavec et al. (2010) demonstrated the implementation of a blueprint for full transition to sustainable manufacturing while Diaz et al. (2010) recommended the redesign of machine tools and the use of operational strategies to enhance green manufacturing. This can be followed up with the environmental performance assessment for the manufacturing process plan as demonstrated by Jiang et al. (2012). Tůma et al. (2014) recommended the prediction approach for electrical energy consumption of the machine tool in the usage stage. For the railway rolling stock, some authors discussed the importance of having the automatic detectors that could assist in recording the amount of failures occurring within the railway rolling stock, this was said to give accuracy on the LCC analysis of a product life. Other authors discussed the importance of supporting RAMS on the critical equipment's by ensuring the RAMS principle is done on design phase. Different model on LCC were shared. Other authors discussed about the importance of recycling the rolling stock equipment to avoid landfill and environmental decay. In addition, in order to enhance the cost, material and energy sustainability during the machining operations, the process design, modelling and optimization of the machining operations and parameters as well as the optimization of the energy consumed during the machining operations have been recommended (Daniyan et al., 2019c, 2019e, 2020d, 2021; Tlhabadira et al., 2021). Table 2 presents the summary of the findings in this study. Articles with a clear focus and approach whose topic align deeply with the study objectives were reported in Table 2. The selected topics were the keywords reported in section 2.2 such as carbon efficiency, life cycle assessment and inventory, life cycle assessment, energy efficiency, machine tool, circular economy and machining operations On the other hand, Table 3 presents the summary of the findings and contributions from the literature reviewed. Articles with significant findings and contributions were captured in Table 3.

Based on the literature reviewed, an integrated life cycle and cyber physical machine tool model was developed (Figure 5).

5. Conclusion

The aim of this study was to review different life cycle models used in the machine tools industry. Some of the approaches employed in the literature reviewed for enhancing the performance of machine tools throughout their life cycles include: LCA principles for low carbon manufacturing, life cycle inventory and impact assessment, reconfiguration of manufacturing systems, Internet of Things (IoTs) and web-based applications, computer aided process planning and cloud platforms, software tool, life cycle oriented services, life cycle costing and profit approach, preventive structuring approach, tool and equipment management approach, technical product service system (t-PSS), real time monitoring approach, green cutting technology, remanufacturing modelling and optimization approach, and multi-criteria decision approach. Some of the approaches reviewed was defining the historical data of the tool history data as a support for the information obtained using the life cycle process model. The aim of this approach is to ensure effective detection and tracking data and its sources. Another approach

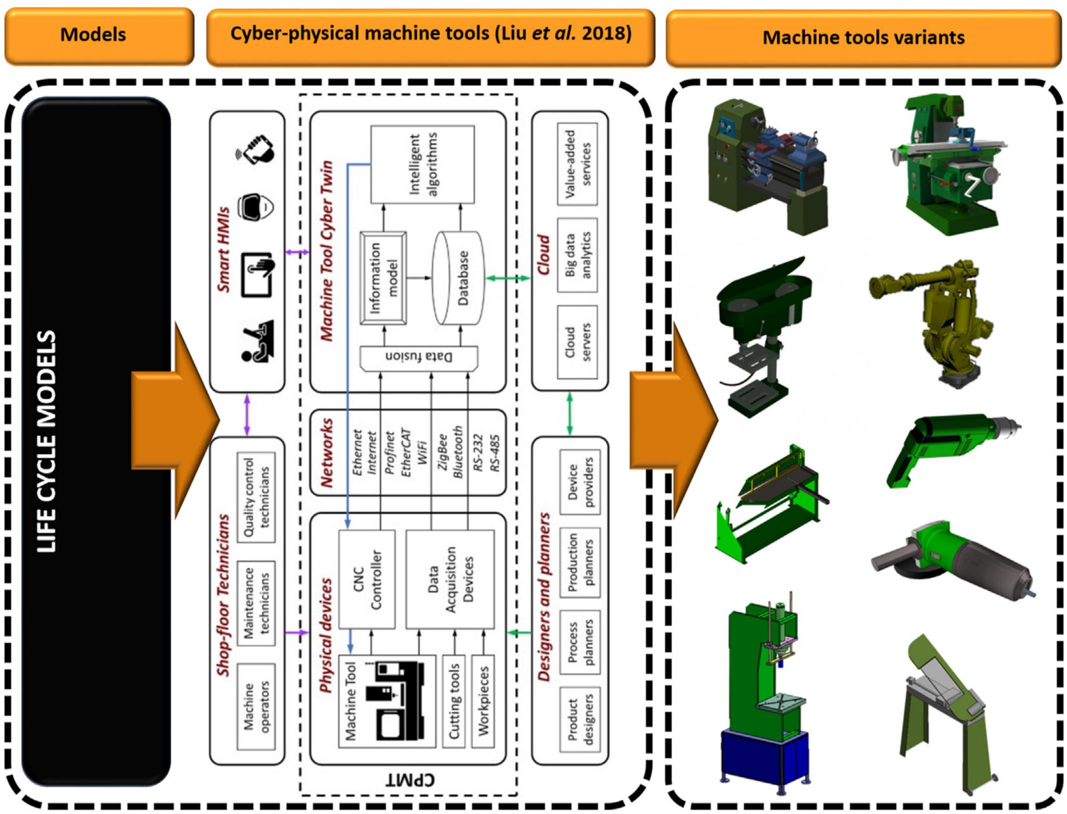

Figure 5. An integrated life cycle and cyber physical machine tool model.

considers the improvement of the efficiency of the resource of a machine tools. This is critical in achieving resource efficiency of machines tools. Furthermore, the LCA approach was considered. Life cycle model in the machine tool industry plays a pivotal role in the overall design stages of the product. It is recommended that manufacturers should consider the possibility of accounting for the effects of the combination of different technologies in one machine on the processing accuracy caused at the early design stage. This paper reviewed a number of articles which addressed methods and models used to manufacture industry tools and ways used to reduce environmental impact thereof. From the articles reviewed, it could be deduced that there are plenty factors that play a role during the life cycle of a machine tools. A combination of two or three of these factors would result in an ideal machine tool life cycle. From the articles reviewed 60% applied LCA approach to reduce energy consumption and environmental impact, and 40% employed other assessment tools. The classification of the articles reviewed was based on six

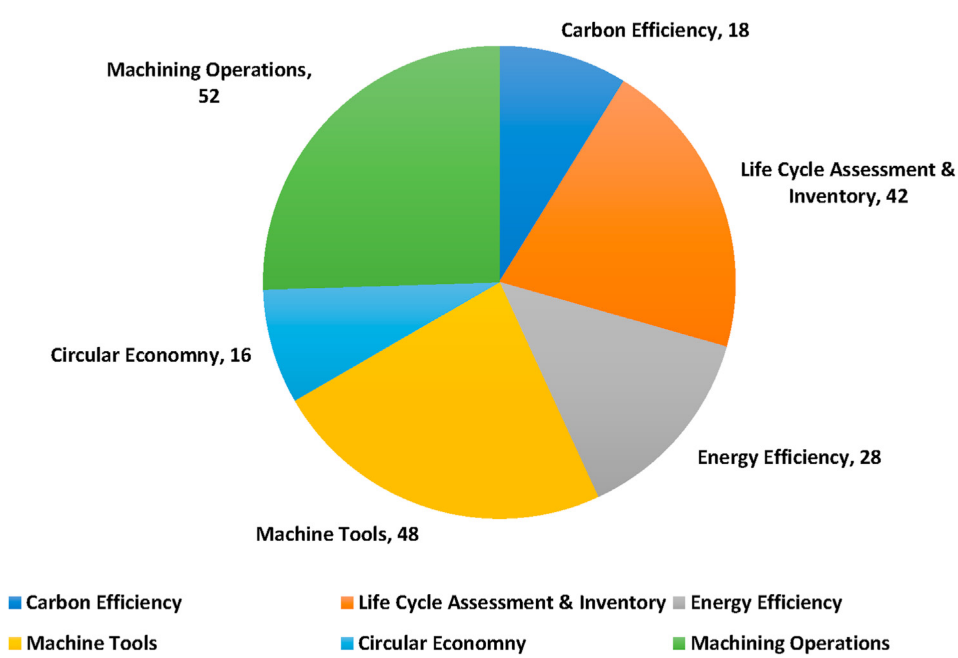

Figure 6. Classification of the literature review based on research focus.

focus namely: machining operation, carbon efficiency, life cycle assessment and inventory, energy efficiency, machine tools and circular economy (see Figure 6).

6. Recommendations

Machine tools are often used in product manufacturing and therefore play an essential role in the sustainability of manufacturing industry. This phenomenon of sustainability requires fundamental changes throughout the value chain, from product design, production processing and business models to the use of raw materials. Machine tools creates a leading share in the machine tool market, so it is very crucial for machine tool industry to implement effective LCA techniques that works in a better way. The machine tools industry should start to fully implement the requirements of the standards and technologies to achieve circular economy, machine tool sustainability, as well as energy and carbon efficiency. Furthermore, the implementation of the LCA approach is recommended. The use of improved resources will salvage the situation of scarce energy which is currently a huge problem for the manufacturing industries. For positive results, it is suggested that ISO 14040 (2006) standard be used in-conjunction with ISO 14044 – Environmental management – Life Cycle Assessment – Requirements and Guidelines. It is about time for machine tools industry to investigate all possibilities that are available to reduce energy consumption especially during the production and usage stage. It is also necessary to implement framework for carbon emission reduction in order to enhance environmental friendliness. This approach will assist in solving the problem of scarce energy resources and promote efficient energy resources. The consideration for the development of light weight product and re-manufacturing can also reduce the amount of carbon emissions.

Declarations

Author contribution statement

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Additional information

No additional information is available for this paper.

References

Abdulrahaman, M.D., Faruk, N., Oloyede, A.A., Surajudeen-Bakinde, N.T., Olawoyin, L.A., Mejabi, O.V., Imam-Fulani, Y.O., Fahm, A.O., Azeez, A.L., 2020. Multimedia tools in the teaching and learning processes: a systematic review. Heliyon 6 (2020), e05312, 1-14.
Abele, E., Fröhlich, B., 2008. High speed milling of titanium alloys. J. Adv. Prod. Eng. Manag. 3, 131–140.
Afsharizand, B., Zhang, X., Newman, S.T., Nassehi, A., 2014. Determination of machinebility considering degradation of accuracy over machine tool life cycle. Procedia CIRP 17, 760–765.
Akbari, J., Oyamada, K., Saito, Y., 2001. December. LCA of machine tools with regard to their secondary effects on quality of machined parts. In: Proceedings Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing. IEEE, pp. 347–352.
Avram, O., Stroud, I., Xirouchakis, P., 2013. Life cycle costs of machine tools. in: green computing as an ecological aid in industry. IGI Global 1905.
Ayed, Y., Germain, G., Melsio, A.-M.P., Kowalewski, P., Locufier, D., 2017. Mpact of supply conditions of liquid nitrogen on tool wear and surface integrity when machining the Ti-6Al-4V titanium alloy. Int. J. Adv. Manuf. Technol. 93 (1-4), 1199–1206.
Azarenko, A., 2009. Technical product-service systems: some implications for the machine tool industry. J. Manuf. Technol. Manag. 20 (5), 700–722.
Azevedo, M., Oliveira, M., Pereira, J.P., Reis, A., 2011. Comparison of two LCA methodologies in the machine-tools environmental performance improvement process. In: Glocalized Solutions for Sustainability in Manufacturing. Springer, Berlin, Heidelberg, pp. 575–580.
Azkarate, A., Ricondo, I., Pérez, A., Martínez, P., 2011. An assessment method and design support system for designing sustainable machine tools. J. Eng. Des. 22 (3), 165–179.
Ball, P.D., Evans, S., Levers, A., Ellison, D., 2009. Zero carbon manufacturing facility—towards integrating material, energy, and waste process flows. Proc. Inst. Mech. Eng B-J Eng. 223 (9), 1085–1096.
Battaïa, O., Dolgui, A., Guschinsky, N., 2017. Decision support for design of reconfigurable rotary machining systems for family part production. Int. J. Prod. Res. 55 (5), 1368–1385.
Bengtsson, M., Kurdve, M., 2016. Machining equipment life cycle costing model with dynamic maintenance cost. Procedia CIRP 48, 102–107.
Bicek, M., Doumont, F., Courbon, C., Pusavec, F., Rech, J., Kopac, J., 2012. Cryogenic machining as an alternative turning process of normalized and hardened AISI 52100 bearing steel. J. Mater. Process. Technol. 212 (12), 2609–2618.
Boothroyd, G., 1988. Fundamentals of Metal Machining and Machine Tools, 28. Crc Press.
Branker, K., Jeswiet, J., Kim, I.Y., 2011. Greenhouse gases emitted in manufacturing a product—a new economic model. CIRP Ann. - Manuf. Technol. 60 (1), 53–56.
Brenner, D., Kleinert, F., Imiela, J., Westkämper, E., 2017. Life cycle management of cutting tools: comprehensive acquisition and aggregation of tool life data. Procedia CIRP 61, 311–316.
Bringmann, B., Bacon, R., Güntert, B., 2014. Dedicated machine tool development for blisk milling. In: New Production Technologies in Aerospace Industry. Springer, Cham, pp. 39–45.
Browne, J., Dubois, D., Rathmill, K., Sethi, S.P., Stecke, K.E., 1984. Classification of flexible manufacturing systems. FMS Mag. 2 (2), 114–117.
Bruzzone, A.A., D'Addona, D.M., Rosciano, I., 2020. Thermoeconomic analysis of LEGO®-Like reconfigurable machine tools. Procedia CIRP 88, 375–380.
Burchart-Korol, D., Fugiel, A., Czaplicka-Kolarz, K., Turek, M., 2016. Model of environmental life cycle assessment for coal mining operations. Sci. Total Environ. 562, 61–72.
Campitelli, A., Cristóbal, J., Fischer, J., Becker, B., Schebek, L., 2019. Resource efficiency analysis of lubricating strategies for machining processes using life cycle assessment methodology. J. Clean. Prod. 222, 464–475.
Cao, H., Li, H., Cheng, H., Luo, Y., Yin, R., Chen, Y., 2012. A carbon efficiency approach for life-cycle carbon emission characteristics of machine tools. J. Clean. Prod. 37, 19–28.
Chanal, H., Duc, E., Ray, P., Hascoet, J.Y., 2007. A new approach for the geometrical calibration of parallel kinematics machines tools based on the machining of a dedicated part. Int. J. Mach. Tool Manufact. 47 (7-8), 1151–1163.
Chatopadhyay, R., 2014. Tool life-cycle improvement through green surface engineering. In: Green Tribology, Green Surface Engineering, and Global Warming. ASM International.
Chen, X., Li, L., Tang, Y., 2018. A framework for energy monitoring of machining workshops based on IoT. In: 51st CIRP Conference on Manufacturing Systems. Science Direct.
Chen, Z., Huang, L., 2019. Application review of LCA (life cycle assessment) in circular economy: from the perspective of PSS (product service system). Procedia CIRP 83, 210–217.
Chukwuma, E.N., 2013. Effects of Machining Parameters and Cooling Strategies on Cutting Forces and Surface Integrity in High-Speed Slot End-Milling of Titanium Alloy. MS Thesis. Missouri University of Science and Technology, Missouri.
Cook, L.R., Stamen, J.S., Miller, B.L., Mason, S.H,Kelly, K.O.N., 2020. CNA Manufacturing Systems Inc, 2020. Flexible tooling system. U.S. Patent Application 16/866,374. [Online] Available at https://uspto.report/patent/app/20200379429. [Accessed 15th January, 2021]
Cordes, S., Hubner, F., Schaarschmidt, T., 2014. Next generation high performance cutting by use of carbon dioxide as cryogenics. Procedia CIRP 14, 401–405.
Courbon, C., Pusavec, F., Dumont, F., Rech, J., Kopac, J., 2013. Tribological behaviour of Ti6Al4V and Inconel 718 under dry and cryogenic conditions–application to the context of machining with carbide tools. Tribol. Int. 66, 72–82.
Daniyan, I.A., Adeodu, A.O., Oladapo, B.I., Daniyan, O.L., Ajetomobi, O.R., 2019a. Development of a reconfigurable fixture for low weight machining operations. Cogent Eng. 6 (1579455), 1–17.
Daniyan, I.A., Mpofu, K., Adeodu, A.O., 2019e. Optimization of welding parameters using Taguchi and response surface methodology for rail car bracket assembly. Int. J. Adv. Manuf. Technol. 100, 2221–2228.
Daniyan, I.A., Mpofu, K., Ramatsetse, B.I., 2020c. The use of Analytical Hierarchy Process (AHP) decision model for materials and assembly method selection during railcar development. Cogent Eng. J. 7 (1833433), 1–23.
Daniyan, I.A., Tlhabadira, I., Daramola, O.O., Phokobye, S.N., Siviwe, M., Mpofu, K., 2020d. Measurement and optimization of cutting forces during MS 200TS milling

process using the response Surface Methodology and dynamometer. Procedia CIRP 88, 288–293.
Daniyan, I.A., Tlhabadira, I., Daramola, O.O., Mpofu, K., 2019b. Design and optimization of machining parameters for effective AISI P20 removal rate during milling operation. Procedia CIRP 84, 861–867.
Daniyan, I.A., Tlhabadira, I., Daramola, O.O., Mpofu, K., 2019c. Design and optimization of machining parameters for effective AISI P20 removal rate during milling operation. Procedia CIRP 84, 861–867.
Daniyan, I.A., Tlhabadira, I., Mpofu, K., Adeodu, A.O., 2020a. Development of numerical models for the prediction of temperature and surface roughness during the machining operation of titanium alloy (Ti6Al14V). Acta Polytechnica. J. 60 (5), 369–390.
Daniyan, I.A., Tlhabadira, I., Mpofu, K., Adeodu, A.O., 2021. Process design and optimization for the milling operation of aluminum alloy (AA6063 T6). Mater. Today: Proceedings 38, 536–543.
Daniyan, I.A., Tlhabadira, I., Phokobye, S.N., Mrausi, S., Mpofu, K., Masu, L., 2020b. Modelling and optimization of the cutting parameters for the milling operation of titanium alloy (Ti6Al4V). In: 2020 IEEE 11th International Conference on Mechanical and Intelligent Manufacturing Technologies (ICMIMT 2020), pp. 68–73. Added to IEEE Xplore.
Daniyan, I.A., Tlhabadira, I., Phokobye, S.N., Siviwe, M., Mpofu, K., 2019d. Modelling and optimization of the cutting forces during Ti6Al4V milling process using the response surface methodology and dynamometer. MM Sci. J. 128, 3353–3363.
de Lacalle, N.L., Mentxaka, A.L. (Eds.), 2008. Machine Tools for High Performance Machining. Springer Science & Business Media.
de Souza Zanuto, R., Hassui, A., Lima, F., Dornfeld, D.A., 2019. Environmental impacts-based milling process planning using a life cycle assessment tool. J. Clean. Prod. 206, 349–355.
Denkena, B., Harms, A., Jacobsen, J., Möhring, H.C., Lange, D., Noske, H., 2006. May. Life-cycle oriented development of machine tools. In: 13th Cooperative Institutional Research Program International Conference on Life Cycle Engineering, pp. 693–698.
Dhananchezian, M., Kumar, P.M., 2011. Cryogenic turning of the Ti–6Al–4V alloy with modified cutting tool inserts. Cryogenics 51, 34–40.
Dhar, N.R., Ahmed, M.T., Islam, S., 2007. An experimental investigation on effect of minimum quantity lubrication in machining AISI 1040 steel. Int. J. Mach. Tool Manufact. 47 (5), 748–753.
Di Orio, G., Cândido, G., Barata, J., Bittencourt, J.L., Bonefeld, R., 2013. Energy efficiency in machine tools-a self-learning approach. In: IEEE International Conference on Systems, Man, and Cybernetics, 2013, pp. 4878–4883.
Diaz, N., Helu, M., Jayanathan, S., Chen, Y., Horvath, A., Dornfeld, D., 2010. Environmental analysis of milling machine tool use in various manufacturing environments. In: Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology, pp. 1–6.
Dilip Jerold, B., Pradeep Kumar, M., 2013. The influence of cryogenic coolants in machining of Ti-6Al-4V. J. Manuf. Sci. Eng. 135, 5–13.
Dilip Jerold, B., Pradeep Kumar, M., 2012. Experimental comparison of carbon-dioxide and liquid nitrogen cryogenic coolants in turning of AISI 1045 steel. Cryogenics 52, 569–574.
Ding, S., Zhang, H., Wu, W., Guo, E., Zhang, Y., Song, A., 2021. A digital and structure-adaptive geometric error definition and modeling method of reconfigurable machine tool. Int. J. Adv. Manuf. Technol. 1–13.
Djavanroodi, F., Omranpour, B., Sedighi, M., 2013. Artificial neural network modeling of ECAP process. Mater. Manuf. Process. 28 (3), 276–281.
Du, Y., Yi, Q., Li, C., Liao, L., 2015. Life cycle oriented low-carbon operation models of machinery manufacturing industry. J. Clean. Prod. 91, 145–157.
Duflou, J., 2008. Efficiency and feasibility of product disassembly: a case-based study. Manuf. Technol. 57, 583–600.
Duflou, J.R., Sutherland, J.W., Dornfeld, D., Herrmann, C., Jeswiet, J., Kara, S., Hauschild, M., Kellens, K., 2012. Towards energy and resource efficient manufacturing: a processes and systems approach. CIRP Ann. - Manuf. Technol. 61, 587–609.
ElMaraghy, H.A., 2005. Flexible and reconfigurable manufacturing systems paradigms. Int. J. Flex. Manuf. Syst. 17 (4), 261–276.
Elshwain, A., Redzuan, N., Yusof, N.M., 2013. Machinability of nickel and titanium alloys under of gas-based coolant-lubricants (CLS)—a review. Int. J. Renew. Energy Technol. 2, 690–702.
Emec, S., Kruger, J., Seliger, G., 2016. Online fault-monitoring in machine tools based on energy consumption analysis and non-invasive data acquisition for improved resource-efficiency. Procedia CIRP 40, 236–243.
Enparantza, R., Revilla, O., Azkarate, A., Zendoia, J., 2006. A life cycle cost calculation and management system for machine tools. In: 13th CIRP International Conference on Life Cycle Engineering, 2, pp. 717–722.
Fallböhmer, P., Rodríguez, C.A., Özel, T., Altan, T., 2000. High-speed machining of cast iron and alloy steels for die and mold manufacturing. J. Mater. Process. Technol. 98 (1), 104–115.
Fang, N., Wu, Q., 2009. A comparative study of the cutting forces in high speed machining of Ti-6Al- 4V and Inconel 718 with a round cutting edge tool. J. Mater. Process. Technol. 209 (9), 4385–4389.
Fernández, D., Sandá, A., Bengoetxea, I., 2019. Cryogenic milling: study of the effect of CO_2 cooling on tool wear when machining inconel 718, Grade EA1N steel and gamma TiAl. Lubricants 7, 1–10.
Feyzi, T., Safavi, S.M., 2013. Improving machinability of Inconel 718 with a new hybrid machining technique. Int. J. Adv. Manuf. Technol. 66, 1025–1030.
Finnveden, G., Hauschild, M.Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., Suh, S., 2009. Recent developments in life cycle assessment. J. Environ. Manag. 91 (1), 1–21.
Fourie, C.J., Tendayi, T.G., 2016. A decision-making framework for effective maintenance management using life cycle costing (LCC) in a rolling stock environment. S. Afr. J. Ind. Eng. 27 (2016), 142–152.
Fratila, D., 2014. Environmentally friendly manufacturing processes in context of transition to sustainable production. Comprehensive Mater. Process. 8 (1), 163–175.
Gadalla, M., Xue, D., 2018. An approach to identify the optimal configurations and reconfiguration processes for design of reconfigurable machine tools. Int. J. Prod. Res. 56 (11), 3880–3900.
Gao, R.X., Wang, P., 2017. Through life analysis for machine tools: from design to remanufacture. Procedia CIRP 59, 2–7.
Garg, G.K., Garg, S., Sangwan, K., 2018. Development of an empirical model for optimization of machining parameters to minimize power consumption. IOP Conf. Ser. *Mater. Sci. Eng.* 346, 012078.
Geissdoerfer, M., Savaget, P., Bocken, N., 2017. The Circular Economy- A new sustainability paradigm? J. Clean. Prod. 143, 757–768.
Grünebaum, T., Hermann, L., Trauth, D., Bergs, T., 2019. Towards sustainable production: a methodology to assess influences between life cycle phases in tool manufacturing. Procedia CIRP 80, 376–381.
Guinée, J.B., Heijungs, R., 2000. Life Cycle Assessment. Kirk-Othmer Encyclopedia of Chemical Technology.
Guinee, J.B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., Rydberg, T., 2011. Life Cycle Assessment: Past, Present, and Future.
Gupta, K., Laubscher, R.F., Davim, J.P., Jain, N.K., 2016. Recent developments in sustainable manufacturing of gears: a review. J. Clean. Prod. 112, 3320–3330.
Hadi, M.A., Ghani, J.A., Haron, C.H., Kasim, M.S., 2013. Comparison between up-milling and down-milling operations on tool wear in milling Inconel 718. Procedia Eng. 68, 647–653.
Hauschild, M.Z., Rosenbaum, R.K., Olsen, S.I., 2018. Life Cycle Assessment, 2018. Springer International Publishing, Cham.
Heeschen, D., Klocke, F., Arntz, K., 2015. Life cycle oriented milling tool management in small scale production. Procedia CIRP 29, 293–298.
Hegab, H.A., Gadallah, M.H., Esawi, A.K., 2015. Modeling and optimization of Electrical Discharge Machining (EDM) using statistical design. Manuf. Rev. 2, 21.
Heijungs, R., Guinée, J.B., Huppes, G., Lankreijer, R.M., Udo de Haes, H.A., Wegener Sleeswijk, A., Ansems, A.M.M., Eggels, P.G., Duin, R. van, Goede, H.P., 1992. Life Cycle Assessment of products.: Guide and Backgroud (Part 1). CML Leiden, Netherlands.
Hellweg, S., Canals, L.M., 2014. Emerging approaches, challenges and opportunities in life cycle assessment. Science 344 (6188), 1109–1113.
Herrmann, C., Thiede, S., Zein, A., Ihlenfeldt, S., Blau, P., 2009. Energy efficiency of machine tools: extending the perspective. In: 42nd CIRP International Conference on Manufacturing System, Grenoble, France, pp. 3–5.
Horne, R., Grant, T., Verghese, K., 2009. Life Cycle Assessment: Principles, Practice, and Prospects. Csiro Publishing.
Hu, S., Liu, F., He, Y., Hu, T., 2012. An on-line approach for energy efficiency monitoring of machine tools. J. Clean. Prod. 27, 133–140.
Huang, S., Cai, L., Zhang, X., 2010. Parallel dedicated machine scheduling problem with sequence-dependent setups and a single server. Comput. Ind. Eng. 58 (1), 165–174.
Huang, S., Wang, G., Yan, Y., 2020. Building blocks for digital twin of reconfigurable machine tools from design perspective. Int. J. Prod. Res. 1–15.
Huang, Y., Bird, R., Heidrich, O., 2009. Development of a life cycle assessment tool for construction and maintenance of asphalt pavements. J. Clean. Prod. 17, 283–296.
Hwang, Y.K., Lee, C.M., Park, S.H., 2009. Evaluation of machinability according to the changes in machine tools and cooling lubrication environments and optimization of cutting conditions using Taguchi method. Int. J. Precis. Eng. Manuf. 10 (3), 65–73.
International Organization for Standardization. (ISO), 2006. Environmental Management – Life Cycle Assessment – Principles and Framework. SABS, Pretoria.
ISO/DIS 14955-1, 2014. International Standard Organisation. Machine tools — environmental evaluation of machine tools — Part 1: design methodology for energy-efficient machine tools. Available at. https://www.iso.org/standard/55294.html. (Accessed 27 September 2019).
Jawahir, I., Bradley, R., 2016. Technological Elements of Circular Economy and Principles of 6R-Based Closed-Loop Material Flow in Sustainable Manufacturing. Elsevier, Lexington.
Jiang, Z.G., Zhang, H., Sutherland, J.W., 2012. Development of an environmental performance assessment method for manufacturing process plans. Int. J. Adv. Manuf. Technol. 58 (5–8), 783–790.
Kamata, Y., Obikawa, T., 2007. High speed MQL finish-turning of Inconel 718 with different coated tools. J. Mater. Process. Technol. 192–193, 281–286.
Kant, G., Sangwan, K.S., 2015. Predictive modelling and optimization of machining parameters to minimize surface roughness using artificial neural network coupled with genetic algorithm. Procedia CIRP 31, 453–458.
Kara, S., Li, W., 2011. Unit process energy consumption models for material removal processes. CIRP Ann. - Manuf. Technol. 60 (1), 37–40.
Kaynak, Y., 2014. Evaluation of machining performance in cryogenic machining of Inconel 718 and comparison with dry and MQL machining. Int. J. Adv. Manuf. Technol. 72 (5–8), 919–933.
Kaynak, Y., Lu, T., Jawahir, I.S., 2014. Cryogenic machining-induced surface integrity: a review and comparison with dry, MQL, and flood-cooled machining. Mach. Sci. Technol. 18, 149–198.
Kim, H.C., Wallington, T.J., 2013. Life-cycle energy and greenhouse gas emission benefits of lightweighting in automobiles: review and harmonization. Environ. Sci. Technol. 47, 6089–6097.
Kishawy, H.A., Hegab, H., Deiab, I., Eltaggaz, A., 2019. Sustainability assessment during machining Ti-6Al-4V with nano-additives-based minimum quantity lubrication (MQL). J. Manuf. Mater. Process 3 (61), 1–12.

Kitchenham, B., Brereton, O.P., Budgen, D., Turner, M., Bailey, J., Linkman, S., 2009. Systematic literature reviews in software engineering–a systematic literature review. Inf. Software Technol. 51 (1), 7–15.

Kjellberg, T., Von Euler-Chelpin, A., Hedlind, M., Lundgren, M., Sivard, G., Chen, D., 2009. The machine tool model—a core part of the digital factory. CIRP Annals 58 (1), 425–428.

Klöpffer, W., 1997. Life cycle assessment. Environ. Sci. Pollut. Control Ser. 4 (4), 223–228.

Koohestani, A., Mo, J., Yang, S., 2014. Stability prediction of titanium milling with data driven reconstruction of phase-space. Mach. Sci. Technol. 18 (1), 78–98.

Koren, Y., 1997. Control of Machine Tools.

Koren, Y., 2006. General RMS characteristics. Comparison with dedicated and flexible systems. In: Reconfigurable Manufacturing Systems and Transformable Factories. Springer, Berlin, Heidelberg, pp. 27–45.

Koren, Y., Heisel, U., Jovane, F., Moriwaki, T., Pritschow, G., Uslow, G., 1999. Reconfigurable manufacturing systems. CIRP Ann. - Manuf. Technol. 4 (2), 527–540.

Kostal, P., Velisek, K., 2010. Flexible manufacturing system. World Acad. Sci. Eng. Technol. 53, 825–829.

Krautzera, F., Pamminger, R., Diverb, C., Wimmera, W., 2015. Assessing the environmental performance of machine tools – case studies applying the 'LCA to go' webtool. Procedia CIRP 29, 502–507.

Kumar, G., Goyal, K.K., Batra, N.K., 2021. Role of performance measures in the configuration selection of reconfigurable manufacturing system. In: Recent Advances in Mechanical Engineering. Springer, Singapore, pp. 621–627.

Landers, R.G., Min, B.K., Koren, Y., 2001. Reconfigurable machine tools. CIRP Annals 50 (1), 269–274.

Lee, B.-E., Suh, S.-H., 2008. An architecture for ubiquitous product life cycle support system and its extension to machine tools with product data model. Int. J. Adv. Manuf. Technol. 42 (5), 606.

Lee, H., Dornfeld, D.A., Jeong, H., 2014. Mathematical model- based evaluation methodology for environmental burden of chemical mechanical planarization process. Int. J. Precis. Eng. Manuf.-Green Tech. 1 (1), 11–15.

Lee, J.Y., Kang, H.S., Noh, S.D., 2012. Simulation-based analysis for sustainability of manufacturing system. Int. J. Precis. Eng. Manuf. 13, 1221–1230.

Li, B., Cao, H., Yan, J., Jafar, S., 2017. A life cycle approach to characterizing carbon efficiency of cutting tools. Int. J. Adv. Manuf. Technol. 93, 3347–3355.

Li, H., Chen, Y., 2014. Machining process monitoring. In: Nee, A. (Ed.), Handbook of Manufacturing Engineering and Technology. Springer, London.

Liao, Y.S., Lin, H.M., Wang, J.H., 2008. Behaviors of end milling Inconel 718 superalloy by cemented carbide tools. J. Mater. Process. Technol. 201 (1-3), 460–465.

Linke, B.S., 2014. Sustainability concerns in the life cycle of bonded grinding tools. CIRP J. Manuf. Sci. Technol. 7 (3), 258–263.

Loglisci, G., Priarone, P.C., Settineri, L., 2013. Cutting tool manufacturing: a sustainability perspective. In: The 11th Global Conference on Sustainable Manufacturing, Berlin, Germany, pp. 252–257, 23rd-25th September.

Mahmoodjanloo, M., Tavakkoli-Moghaddam, R., Baboli, A., Bozorgi-Amiri, A., 2020a. Flexible job shop scheduling problem with reconfigurable machine tools: an improved differential evolution algorithm. Appl. Soft Comput. 94, 106416.

Mahmoodjanloo, M., Tavakkoli-Moghaddam, R., Baboli, A., Bozorgi-Amiri, A., 2020b. Dynamic distributed job-shop scheduling problem consisting of reconfigurable machine tools. In: IFIP International Conference on Advances in Production Management Systems. Springer, Cham, pp. 460–468.

Matthews, H.S., Hendrickson, C.T., Matthews, D.H., 2014. Life Cycle Assessment. (Quantitative Approaches for Decisions that Matter). Open access textbook. https://www.lcatextbook.com/. (Accessed 27 September 2019).

Mayr, J., Jedrzejewski, J., Uhlmann, E., Donmez, M.A., Knapp, W., Härtig, F., Wendt, K., Moriwaki, T., Shore, P., Schmitt, R., Brecher, C., 2012. Thermal issues in machine tools. CIRP Annals 61 (2), 771–791.

Merkisz-Guranowska, A., Merkisz, J., Jacyna, M., Stawecka, H., Wasiak, M., 2014. Recycling guidelines of the rolling stock. In: POMBO, J. (Ed.), Railway Technology: Research, Development and Maintenance, Stirlingshire, Scotland. Civil-Comp Press.

Mert, G., Bohr, C., Waltemode, S., Aurich, J.C., 2014. Increasing the resource efficiency of machine tools by life cycle oriented services. Procedia CIRP 15, 176–181.

Mhamdi, M.B., Boujelbene, M., Bayraktar, E., Zghal, A., 2012. Surface integrity of titanium alloy Ti-6Al-4V in ball end milling. Phy. Proc. 25, 355–362.

Ming, Z., Zeng, C., Wang, G., Hao, J., Yan, Y., 2020. Ontology-based module selection in the design of reconfigurable machine tools. J. Intell. Manuf. 31 (2), 301–317.

Mori, M., Fujishima, M., 2009. Reconfigurable machine tools for a flexible manufacturing system. In: Changeable and Reconfigurable Manufacturing Systems. Springer, London, pp. 101–109.

Mori, M., Fujishima, M., Inamasu, Y., Oda, Y., 2011. A study on energy efficiency improvement for machine tools. CIRP Annals 60 (1), 145–148.

Murena, E., Mpofu, K., Makinde, A.,O., Trimble A, J., Wang, X.,V., 2018. Web-based process planning system concept selection using Weighted Decision Matrix and Analytical Hierarchy Process: a case study of sheet metal bending operations. Proc. Manuf. 33, 462–469.

Murena, E., Mpofu, K., Trimble, J., Gwangwava, N., 2017. Model for developing a feature recogntion system for A reconfigurable bending press machine. Procedia CIRP 63, 533–538.

Murray, A., Skene, K., Haynes, K., 2017. The Circular Economy: an Interdisciplinary Exploration of the Concept and Application in a Global Context, 140. Springer Science and Business Media, pp. 369–380.

Neugebauer, R., Denkena, B., Wegener, K., 2007. Mechatronic systems for machine tools. CIRP Annals 56 (2), 657–686.

Okafor, A.C., Jasra, P.M., 2018. Effects of cooling strategies and tool coatings on cutting forces and tooth frequency in high-speed down-milling of Inconel-718 using helical bull-nose solid carbide end-mills. Int. J. Adv. Manuf. Technol. 97, 2301–2318.

Okafor, A.C., Jasra, P.M., 2019. Effects of milling methods and cooling strategies on tool wear, chip morphology and surface roughness in high-speed end-milling of Inconel-718. Int. J. Mach. Mach. Mater. 21 (1/2), 3.

Okafor, A.C., Aramalla, S., 2006. Modeling of cutting forces in high speed end milling of titanium alloys using finite element analysis and mechanistic model. In: Proceedings of the 9th CIRP International Workshop on Modeling of Machining Operations, Ljubljana, Slovenia (2006), pp. 219–226.

Olabanji, O.M., Mpofu, K., 2020. Design sustainability of reconfigurable machines. IEEE Access 8, 215956–215976.

Oshel, G., Graham, J., Farrow, G.J. ,Nguyen, N.H., ATS Automation Tooling Systems Inc, 2020. System and method for flexible manufacturing. U.S. Patent Application 16/503,912. [Online] Available at https://uspto.report/patent/app/20200009634. [Accessed 12th November, 2020].

Park, K.-H., Yang, G.-D., Suhaimi, M., Lee, D.-Y., Kim, T.-G., Kim, D.-W., 2015. The effect of cryogenic cooling and minimum quantity lubrication on end milling of titanium alloy Ti-6Al-4V. J. Mech. Sci. Technol. 29 (12), 5121–5126.

Patpatiya, P., Bhatnagar, V., Tyagi, H., Anand, N., 2021. Programmable logic controller controlled 360 degree flexible drilling machine. In: Advances in Electromechanical Technologies. Springer, Singapore, pp. 937–947.

Peña, C., Civit, B., Gallego-Schmid, A., Druckman, A., Caldeira-Pires, A., Weidema, B., Mieras, E., Wang, F., Fava, J., i Canals, L.M., Cordella, M., 2021. Using life cycle assessment to achieve a circular economy. Int. J. Life Cycle Assess. 1–6.

Pennington, D.W., Potting, J., Finnveden, G., Lindeijer, E., Jolliet, O., Rydberg, T., Rebitzer, G., 2004. Life cycle assessment Part 2: current impact assessment practice. Environ. Int. 30 (5), 721–739.

Pereira, O., Rodriguez, A., Ayesta, I., Barreiro, J., Fernandez-Abia, A.I., de Lacalle, L.N.L., 2016. A cryo lubri-coolant approach for finish milling of aeronautical har-to-cut materials. Int. J. Mechatron. Manuf. Syst. 9, 370–383.

Pereira, O., Rodriguez, A., Ayesta, I., Urbikain, G., Fernandez-Valdivielso, A., de Lacalle, L.N.L., Calleja, A., 2017. Internal cryolubrication approach for Inconel 718 milling. Procedia Manuf. 13, 89–93.

Pervaiz, S., Deiab, I., Darras, B., 2013. Power consumption and tool wear assessment when machining titanium alloys. Int. J. Precis. Eng. Manuf. 14 (6), 925–936.

Phuluwa, H.S., Mpofu, K., Trimble, J.A., 2019. Cellular de-manufacturing layout in a rail industry: end-of- life components reusability. Proc. Manuf. 38, 307–315.

Priarone, P.C., 2016. Quality-conscious optimization of energy consumption in a grinding process applying sustainability indicators. Int. J. Adv. Manuf. Technol. 86, 2107–2117.

Pusavec, F., Krajnik, P., Kopac, J., 2010. Transitioning to sustainable production—Part I: application on machining technologies. J. Clean. Prod. 18, 174–184.

Raman, A.V., Haapala, K.R., Raoufi, K., Linke, B.S., Bernstein, W.Z., Morris, K.C., 2020. Defining near-term to long-term research opportunities to advance metrics, models, and methods for smart and sustainable manufacturing. Smart Sustain. Manuf. Syst. 4 (2), 1–37.

Rashid, R.R., Sun, S., Wang, G., Dargusch, M., 2012. An investigation of cutting forces and cutting temperatures during laser-assisted machining of the ti-6cr-5mo-5v-4al beta titanium alloy. Int. J. Mach. Tool Manufact. 63, 58–69.

Reap, J., Roman, F., Duncan, S., Bras, B., 2008. A survey of unresolved problems in life cycle assessment. Int. J. Life Cycle Assess. 13 (5), 374–388.

Relea, E., Weiss, L., Wegener, K., 2019. Experimental study on the geometrical and dimensional stability of natural stone sorts for precision machinery. Procedia CIRP 80, 89–94.

Roberts, C., Goodall, R., 2009. Strategies and techniques for safety and performance monitoring on railways. In: Proceedings of the 7th IFAC Symposium on Fault Detection. Supervision and Safety of Technical Processes, pp. 746–755.

Rotella, G., Dillon Jr., O.W., Umbrello, D., Settineri, L., Jawahir, I.S., 2014. The effects of cooling conditions on surface integrity in machining of Ti6Al4V alloy. Int. J. Adv. Manuf. Technol. 71 (1–4), 47–55.

Russell, G., 2014. Budget Phase. New York: McGraw-Hill Education.

Santos, J.P., Oliveira, M., Almeida, F.G., Pereira, J.P., Reis, A., 2011. Improving the environmental performance of machine-tools: influence of technology and throughput on the electrical energy consumption of a press-brake. J. Clean. Prod. 19 (4), 356–364.

Schmida, A., Löwer, M., Katzwinkel, T., Schmidt, W., Siebrecht, J., Feldhusen, J., Brecher, C., du Bois-Reymond, F., Rey, J., 2016. Life cycle of multi technology machine tools – modularization and integral design. Procedia CIRP 50, 719–726.

Seloane, W.T., Mpofu, K., Ramatsetse, B.I., Modungwa, D., 2020. Conceptual design of intelligent reconfigurable welding fixture for rail car manufacturing industry. Procedia CIRP 91, 583–593.

Shan, C., Zhang, X., Shen, B., Zhang, D., 2019. An improved analytical model of cutting temperature in orthogonal cutting of Ti6Al4V. Chin. J. Aeronaut. 32 (3), 759–769.

Sharma, A.K., Singh, R.K., Dixit, A.R., Tiwari, A.K., 2016. Characterization and experimental investigation of Al_2O_3 nanoparticle based cutting fluid in turning of AISI 1040 steel under minimum quantity lubricant (MQL). Mater. Today Proceed. 3, 1899–1906.

Shokrani, A., Dhokia, V., Newman, S.T., 2016. Investigation of the effects of cryogenic machining on surface integrity in end milling of Ti-6Al-4V titanium alloy. J. Manuf. Process. 21, 172–179.

Shokrani, Dhokia, V., Newman, S.T., Imani-Asrai, R., 2012. An initial study of the effect of using liquid nitrogen coolant on the surface roughness of inconel 718 nickel-based alloy in CNC milling. Procedia CIRP 3, 121–125.

Sibanda, V., Mpofu, K., Trimble, J., Kanganga, M., 2019. Engineering design featuring the life cycle approach for reconfigurable machine tool. 29th CIRP Design. Procedia CIRP 84, 948–953.
Sidik, N.A.K., Samion, S., Ghaderian, J., 2017. Recent progress on the application of nanofluids in minimum quantity lubrication machining: a review. Int. J. Heat Mass Tran. 108, 79–89.
Sihag, N., Sangwan, K.S., 2019. Development of a sustainability assessment index for machine tools. Procedia CIRP 80, 156–161.
Silva, D.A.L., Filleti, R.A.P., Christoforo, A.L., Silva, E.J., Ometto, A.R., 2015. Application of life cycle assessment (LCA) and design of Experiments (DOE) to the monitoring and control of a grinding process. Procedia CIRP 292 (15), 508–513.
Simonen, K., 2014. Life Cycle Assessment. Routledge.
Slapnik, M., Istenic, D., Pintar, M., Udovc, A., 2015. Extending life cycle assessment normalization factors and use of machine learning – a Slovenian case study. Ecol. Indicat. 50, 161–172.
Srinivasan, R.S., Ingwersen, W., Trucco, C., Ries, R., Campbell, D., 2014. Comparison of energy-based indicators used in life cycle assessment tools for buildings. Build. Environ. 79, 138–151.
Stecke, K.E., 1985. Design, planning, scheduling, and control problems of flexible manufacturing systems. Ann. Oper. Res. 3 (1), 1–12.
Strano, M., Chiappini, E., Tirelli, S., Albertelli, P., Monno, M., 2013. Comparison of Ti6Al4V machining forces and tool life for cryogenic versus conventional cooling. Proc. IME B J. Eng. Manufact. 228, 191–202.
Tapoglou, N., Lopez, M.I.A., Cook, I., Taylor, C.M., 2017. Investigation of the influence of CO2 cryogenic coolant application on tool wear. Procedia CIRP 63, 745–749.
Tlhabadira, I., Daniyan, I.A., Machaka, R., Machio, C., Masu, L., VanStaden, L.R., 2019. Modelling and optimization of surface roughness during AISI P20 milling process using taguchi method. Int. J. Adv. Manuf. Technol. 102 (9-12), 3707–3718.
Tlhabadira, I., Daniyan, I.A., Masu, L., Mpofu, K., 2021. Development of a model for the optimization of energy consumption during the milling operation of titanium alloy (Ti6Al4V). Mater. Today: Proceedings 38, 614–620.
Triebe, M.J., Zhao, F., Sutherland, J.W., 2019. Achieving energy efficient machine tools by mass reduction through multi-objective optimization. Procedia CIRP 80, 73–78.
Tůma, J., Blecha, P., Zahálka, J., Tůma, Z., 2014. Prediction method for electrical energy consumption of the machine tool in the usage stage. In: Proceedings of the 16th International Conference on Mechatronics-Mechatronika, pp. 248–253.
Uriarte, L., Zatarain, M., Axinte, D., Yagüe-Fabra, J., Ihlenfeldt, S., Eguia, J., Olarra, A., 2013. Machine tools for large parts. CIRP Annals 62 (2), 731–750.
Valdes, E., Dequidt, A., Maiza, N., Leroy, J.P., Castelain, J.M., 1997. A methodology for the design of servo-systems dedicated to machine-tools. In: Integrated Design and Manufacturing in Mechanical Engineering. Springer, Dordrecht, pp. 515–524.
Vijayaraghavan, A., Dornfeld, D., 2010. Automated energy monitoring of machine tools. CIRP Annals 59 (1), 21–24.
Wang, G., Shang, X., Yan, Y., Allen, J.K., Mistree, F., 2018. A tree-based decision method for the configuration design of reconfigurable machine tools. J. Manuf. Syst. 49, 143–162.
Wang, G., Wang, S., Huang, S., Shang, X., Yan, Y., 2020. Feature-driven design of reconfigurable machine tool configurations. In: Reconfigurable Manufacturing Systems: from Design to Implementation. Springer, Cham, pp. 89–122.
Wegener, K., Bleicher, F., Krajnik, P., Hoffmeister, H.-W., Brecher, C., 2017. Recent developments in grinding machines. CIRP Annals 66 (2), 779–802.
Westerkamp, T.A., 2013. How to optimize precision machine tool life cycle. In: Maintenance Manager's Standard Manual, fifth ed. BNI Building News, p. 338.
Winter, M., Ibbotson, S., Kara, S., Herrmann, C., 2015. Life cycle assessment of cubic boron nitride grinding wheels. J. Clean. Prod. 107, 707–721.
Wu, H., Shi, Y., Xia, Q., Zhu, W., 2014. Effectiveness of the policy of circular economy in China: a DEA-based analysis for the period of Eleventh five-year-plan. Resour. Conserv. Recycl. 83 (1), 63–75.
Xing, K., Liu, X., Liu, Z., Mayer, J.R.R., Achiche, S., 2021. Low-cost precision monitoring system of machine tools for SMEs. Procedia CIRP 96, 347–352.
Xu, X.W., Newman, S.T., 2006. Making CNC machine tools more open, interoperable and intelligent—a review of the technologies. Comput. Ind. 57 (2), 141–152.
Yi, Q., Li, C.B., Zhang, X.L., Liu, F., Tang, Y., 2015. An optimization model of machining process route for low carbon manufacturing. Int. J. Adv. Manuf. Technol. 80 (5-8), 1181–1196.
Youssef, H.A., El-Hofy, H., 2008. Machining Technology: Machine Tools and Operations. CRC Press.
Zein, A., Li, W., Herrmann, C., Kara, S., 2011. Energy efficiency measures for the design and operation of machine tools: an axiomatic approach. In: Glocalized Solutions for Sustainability in Manufacturing. Springer, Berlin, Heidelberg, pp. 274–279.
Zendoia, J., Woy, U., Ridgway, N., Pajula, T., Unamuno, G., Olaizola, A., Fysikopoulos, A., Krain, R., 2014. A specific method for the life cycle inventory of machine tools and its demonstration with two manufacturing case studies. J. Clean. Prod. 78, 139–151.
Zhang, H., Zheng, L., Chen, X., Huang, H., 2016. A novel reconfigurable assembly jig based on stable agile joints and adaptive positioning-clamping bolts. Procedia CIRP 44, 316–321.
Zhang, J., Zhang, C., Guo, S., Zhou, L., 2012. Research on tool wear detection based on machine vision in end milling process. Prod. Eng. 6 (4-5), 431–437.
Zhao, W., He, N., Li, L., 2007. High speed milling of Ti6Al4V alloy with minimal quantity lubrication. Key Eng. Mater. 375–376, 435–439.
Zhao, Y., Ming, Z., 2019. Solutions to mitigate the impact of electrical machines on resources and the environment. Procedia CIRP 733–738.
Zheng, J., Mi, Z., Coffman, D.'M., Milcheva, S., Shan, Y., Guan, D., Wang, S., 2019. Regional development and carbon emissions in China. Energy Econ. 81, 25–36.
Zheng, L., Yang, X.M., Zhang, Z.H., Liu, T.I., 2008. A web-based machining parameter selection system for life cycle cost reduction and product quality enhancement. Comput. Ind. 59, 254–261.
Zhou, L., Li, J., Li, F., Meng, Q., Li, J., Xu, X., 2016. Energy consumption model and energy efficiency of machine tools: a comprehensive literature review. J. Clean. Prod. 112, 3721–3734.