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Chapter 1

Sustainable Solid Waste Recycling

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Additional information is available at the end of the chapter

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Abstract

Nowadays, overpopulation and rapid development of industries and lifestyle lead to an increase in the consumption of natural resources and reduction of their resource. On the other hand, humans have always produced waste and disposed it in some way, which influence the environment. Therefore, the increase in waste that was generated by the industrial factories and the human activities needs to be managed. For this reason, scientists have discovered new types of engineering that include sustainable engineering and green engineering to reduce energy and natural resource consumptions. The main goal of this chapter is to explain the main advantages of sustainable manufacturing process and their effects in minimizing or eliminating production and processing wastes through eco-efficient practices, and it encourages adopting new environmental technologies. Therefore, this chapter offers a short introduction about sustainability, sustainable manufacturing process, solid-state management, and two case studies that include experimental works for recycling plastic waste and nonferrous waste materials by using sustainable solid waste recycling process to reduce waste and eliminate its influence on the environment.

Keywords: sustainability, waste, recycling, solid state, environment, plastic

1. Introduction

Nowadays, overpopulation and rapid development of industries and lifestyle lead to an increase in the consumption of natural resources and reduction of their resource. On the other hand, humans have always produced waste and disposed it in some way, which influence the environment. Therefore, the increase in waste that was generated by the industrial factories and the human activities needs to be managed. For this reason, scientists have discovered new types of engineering that include sustainable engineering and green engineering to reduce energy and natural resources consumptions. The idea of sustainability has a quantifiable unit, which refers to three pillars of social, environmental, and economic. They focus on the environmental policies, which increasingly require the reduction, reuse, and recycling of waste for contributing to closing the loop of material use throughout economy by providing waste-derived materials as inputs for production.

Sustainable manufacturing process and solid waste management are used for conserving valuable natural resources, preventing the unnecessary emission of gas and protecting public health. The main goals include reducing environmental impacts and offering economic opportunities. Solid-state recycling process becomes an effective and powerful methodology to realize the green state forming from recyclable waste to useful parts. The developed process can be considered as a typical green forming or environmentally manufactured process. It has many benefits including simple, cost-effective, and energy saving and can be clean recycled as it does not harm the environment.

The application of plastic materials and their composites continues to grow rapidly due to their low cost and ease of manufacturing. Therefore, a high amount of waste plastic is being accumulated, which creates a big challenge for their disposal. Disposal the sustainability of plastic for a wide variety of application, organizations are faced with the growing problem of finding alternative methods for disposing a large volume of waste packages. Disposal of plastic waste in environment is considered to be a big problem due to its very low biodegradability and presence of large quantity. Moreover, different types and sizes of metal chips are produced during manufacturing process of metal products. The generated chips had been recycled by traditional methods that include remelting and casting processes, which lead to loss of parts of chips due to their oxidation because of their size and weight. The traditional recycling process becomes an expensive method because it consumed high energy and generated high pollution. Furthermore, energy conservation and environment preservation are a challenging task worldwide. Therefore, sustainable manufacturing process is a promising technology to reduce the waste and cost as well as reducing the usage of primary natural resource by developing and improving lightweight materials. Solid-state metal conversion is one of the most important processes that can be used to eliminate the required energy for melting due its ability to produce solid parts directly from solid chips. Sustainable development is the development that meets the needs of the present without compromising on the ability of future generations to meet their own needs.

The main goal of this chapter is to explain the main advantages of sustainable manufacturing process and their effects in minimizing or eliminating production and processing wastes through eco-efficient practices, and it encourages adopting new environmental technologies. Therefore, this chapter discusses short introduction about sustainability, sustainable manufacturing process, solid waste management, and two case studies that include experimental works for recycling plastic waste and nonferrous waste materials by using sustainable manufacturing process to reduce waste and eliminate its influence on the environment. In addition, the main method for saving energy and materials, reduce waste, and elimination pollution well defined as well as the process that used to transfer the waste into useful products and their results will explain.

2. Sustainability

Humans that require everything for their survival and well-being depend directly or indirectly on the natural environment. Our health, economy and security are required high quality of environment. Sustainability is being used by international organizations as a common approach to address the three sustainability pillars that include social, environmental, and economic issues. The potential economic value of sustainability is recognized to not merely decrease environmental risks but also to optimize the social and economic benefits of environmental protection. Sustainability is used to create and maintain conditions under which humans and nature can exist in productive harmony that permit fulfilling the social, economic and other requirements of present and future generations [1].

Sustainability has been applied in the field of engineering, manufacturing, design, technology, economics, environmental stewardship and health. Therefore, sustainable development becomes a key objective in human development due to increasing human activity. For that reason, sustainable manufacturing process requires balancing and integrating economic, environmental and societal objectives [1].

The growing identification of sustainability as both a process and a goal ensures long-term human well-being. The recognition that current approaches for decreasing existing risks, however successful are not capable of avoiding the complex problem. But current and future human generations at risk due to overpopulation, the gaps between rich and poor, reduction of natural resources, biodiversity loss and climate change will reduce. Human beings are at the center of concern for sustainable development. The principle makes clear that human well-being and quality of life is the objective of sustainability. Therefore, sustainable is defined as meeting the needs of the present without compromising on the ability of future generations to meet their own needs. It is improving the quality of human life while living within the carrying capacity of supporting ecosystems, through vague conveys: the idea of sustainability having quantifiable limits.

A large number of tools can be applied to address component parts of an analysis. Several principles are important in applying the suitable sustainability tools. They can be usefully applied in the sustainability assessment and management process. Small subset of the most appropriate tools includes risk assessment, life cycle assessment, benefit cost analysis, ecosystem services valuation, integrated assessment models, sustainability impact assessment, and environmental justice tools [2].

Risk assessment is a tool widely used for characterizing the adverse human health and ecologic effects of exposures. Therefore, risk assessments can be classified into four major steps that include a hazard identification, close-response assessment, exposures assessment, and risk characterization. On the other hand, life cycle assessment is defined as a cradle to grave analysis or cradle to cradle of environment impacts of various products, to determine how changes in processes could lower the environmental impact, and to compare the environmental impacts of different products [2].

The main tool that is widely used for evaluating the net benefits of alternative decisions is the benefit cost analysis. It measures the change in welfare for each individual affected by policy choice. It is used to find a social net benefit and then rank the alternative. On the other hand, ecosystem services are goods and services that contribute to human well-being and the valuation measured in money terms can be used in benefit cost analysis to capture a more complete picture of the net benefit of alternative actions. On the other hand, sustainable impact assessment can be used to analyze the probable effects of a particular project on the three pillars of sustainability. It is used to develop integrated policies that take full account of the three sustainable development dimensions and long-term considerations of those policies [2].

3. Solid waste management

Waste is defined as any substances or objects that the holder discards or intends to discard. It can be classified into non-hazardous waste such as packaging waste and hazardous waste like chemical waste [3]. Therefore, waste disposal should be seen as a last resort. Not only does waste disposal mean that valuable resources and energy are being thrown away but also biodegradable waste in landfill can emit methane. On the other hand, landfill space is becoming restricted.

Waste management has become a significant business issue for small businesses in recent years. All goods and products contain raw materials and energy. If they are discarded, we are effectively throwing away valuable natural resources. Waste disposal can also have adverse impacts on local air pollution and greenhouse gas emissions. Therefore, waste management can be defined as the collection, transport, processing, recycling and monitoring of waste materials that are produced by human. It is generally undertaken to reduce their effect on health, environment and carried out to recover resources from it [3].

The manufacturing strategy for environmentally kind products involves design process, which accounts for environmental impacts over the life of the products. Therefore, environmental improvements are related to manufacturing processes that are linked to reduction, reuse, recycling, and remanufacturing. However, eco-friendly comprises eco-design, eco-extraction, eco-manufacturing, eco-construction, eco-rehabilitation, eco-maintenance, eco-demolition, and socio-economic empowerment. Recently, sustainable eco-friendly road construction is increasingly receiving more attention worldwide. It is green our infrastructures of road constructing and reducing environmental impacts. It is also spurred by the increase in demand for eco-cities and eco-developments that are more environmentally friendly. Eco-friendly road construction can also be viewed as a response of stakeholders to the calls for sustainable development which arose from the growing awareness of the negative impact of road construction on our environments.

The quality of recycling wastes varies because of insufficient information on the properties of the manufacturing products, and lack of acknowledgement for using recycling materials as input material in new construction products, as well as lack of acknowledgement about the important elements and necessary actions for recycling the wastes.

The difficulties encountered in recycling are labor costs, lack of government awareness and support toward recycling, and limited real-life applications of recycled materials to allow for evaluation for their performance. The main benefits of recycling are reduction of material hauling and disposal costs and preservation of landfill capacity which lead to elongation of landfill design life and sometimes cheaper materials compared to virgin materials. Recycling helps in greening our infrastructures by conserving natural resources, decreasing energy use, reducing greenhouse gas emissions and air pollution, reducing the extraction of the virgin materials and minimizing their consumption, and environmental protection [4].

Different kinds of materials can be recycled in road construction such as fly ash, silica fume, ground granulated, blast furnace slag, reclaimed asphalt pavement, and plastic wastes such as polystyrene, polyethylene, and reclaimed concrete. Recycling waste materials can function as fine and coarse aggregates and supplementary cementing materials depending on the properties of the wastes intended to be optimized and the desired applications [4].

Eco-friendly road construction is one that is beneficial or non-harmful to the environment and is energy and resource efficient. To be eco-friendly, it must imbibe certain basic elements, namely eco-friendly, eco-extraction, eco-manufacturing, eco-construction, eco-rehabilitation, eco-maintenance, and eco-demolition. Utilization of waste materials will minimize negative impact on the environment and minimize the use of virgin materials [4].

An increasing in global plastic production and consumption due to increase or over population, development, and industrialization as well as lifestyle changes, the challenges posed by plastic wastes, which constitute of 25% of municipal solid waste. On the other hand, utilization of wastes from polyethylene constitutes 60% of plastic bottles. As a result, product packaging becomes the major contributor to environmental waste. Therefore, sustainable waste management will help to

1. Minimize waste.
2. Reuse waste.
3. Recycle waste for further use.
4. Energy recovery.
5. Disposal.

4. Sustainable manufacturing process

Sustainable manufacturing is defined as the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound [1, 5, 6]. Traditionally, manufacturing is defined as the process that is used to describe the physical transformation of materials or converting input materials into products. Sustainable production emphasizes a life cycle perspective in the manufacture, recycling, and disposal of goods and services, instead of the traditional focus on discrete activities. It encourages continuous to improved efficiency of using energy and resources [5]. Therefore, sustainable production is defined as the creation of goods and services using processes and systems that are non-polluting, conserving energy and natural resources [1, 6]. Nowadays, sustainable manufacturing has evolved beyond the life cycle view and the key business has benefits from sustainable manufacturing, which includes financial performance, business excellence, and relationship with stakeholders as follows [6]:

A. Financial performance:

- Increase sale.
- Improve efficiency and productivity by reducing resource use and waste.
- Reduce dependence and expensive or hazardous materials.

B. Business excellence:

- Stay ahead of regulations.
- Win access to capital.
- Gain strategic foresight.

C. Relationship with stakeholders:

- Enhance repetition.
- Demonstrating green know-how and setting a positive example.
- Improve employee's morale and retention.
- Build better community relations.

Companies across the world face increased costs in materials, energy and compliance coupled with higher expectations of customers, investors and local communities because they throw away valuable natural resources as waste. Waste disposal has adverse impacts on the local air pollution and greenhouse gas emissions. Sustainable waste management is vital for

- saving valuable natural resources.
- avoiding unnecessary emission of gas.
- protective public health and natural ecosystems.

5. Case study

There are two case studies conducted in the field of recycling of solid wastes materials that included polyethylene waste and non-ferrous metal waste. They were used to study the possibility to use waste materials as a raw material for producing solid parts or use as an additive material to improve the properties of products. They used and produced by applying a sustainable manufacturing process that reduces the waste, cost, environmental pollution and impact.

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5.1. Recycling of polyethylene waste

The amount of plastic waste that is destined to the landfills is increasing each year. Disposal of plastic waste in the environment is considered to be a big problem due to its very low biodegradability and presence of large quantities. Therefore, finding alternative methods of disposing waste by using friendly methods is becoming a major research issue [7–10].

Humans have always produced waste and disposed them in some way. Nowadays, the types and amounts of waste produced and the method of disposal are changed, as well as the human values and awareness of what should be done with it. The applications of plastic materials and their composites are still growing rapidly due to their low cost and ease of manufacture. Therefore, a high amount of waste plastic is being accumulated, which creates big challenges for their disposal [7, 10].

One of the environmental issues in most regions of Iraq is the large number of package made from polyethylene materials such as shampoo sachets, carry-bags, nitro packs, milk and water pouches, and vegetable packages, and so on, which are deposited in domestic waste and landfills. The largest component of the plastic waste is polypropylene, polyethylene terephthalate, and polystyrene [7, 9, 10].

Today, sustainability has obtained top priority in construction industry. Recently, plastics were used to prepare coarse aggregates, thereby providing a sustainable option to deal with the plastic waste. Therefore, recycling of plastic waste is an important topic in order to decrease environmental pollution and prevent waste of resources [9–11].

Recently, plastic waste is one component of municipal solid wastes, which is becoming a major research issue to study the possibility of disposal of the waste in mass concrete especially in self-compacting concrete, in lightweight concrete, and in pavements. It can be used as a component of a composite construction material, as an inorganic filling material, and an aggregate of concrete [8–11].

Recycling of plastic waste in concrete has advantages since it is widely used and has a long service life, which means that the waste is being removed from the waste stream for a long period. Moreover, using post-consumer plastic waste in concrete will not only be its safe disposal method but may improve the concrete properties like tensile strength, chemical resistance, drying shrinkage and creep on short- and long-term basis [7, 10].

They maximize the benefits of economy, environment, and society and minimize adverse impact. This leads to an increase in the efficiency of a process and reduces the amount of pollution, which will shift the industrial processes from open-loop system to closed-loop systems where the resource wastes become inputs for new processes [10, 12].

Plastic has different properties such as durable and corrosion resistant, good isolation for cold, heat and sound, saving energy, economical, has a longer life and light weight. Solid-state recycling process is proposed to realize the direct recycling of polyethylene as the green engineering forming technology [6, 8, 9]. Researchers have found that there is a possibility to produce a good quality of cement by using the waste of polyethylene. The results show that the addition of polymeric material in a fraction less than 10% in the volume of cement matrix does not imply a significant variation in the mechanical properties of cement. However, the density and compression strength of cement decreased when the percentage of polyethylene aggregate exceeds 50% by volume as well as when the weight of normal concrete had been reduced [13–18].

5.1.1. Polyethylene waste plastic cement

Polyethylene waste materials are used to produce plastic cement directly from solid state to improve the mechanical properties and workability of products. High-density polyethylene waste is mixed with Portland cement to investigate the possibility to produce plastic cement and study the effect of replacing sand by fine polyethylene waste with different percentage on the properties of product.

High-density polyethylene boxes or crates have been collected from municipal and landfills as a waste of human activities. Then, they are cut into small size by using a special cutting and grinding machine to get fine particles. The result grinding polyethylene wastes are sieved to separate the fine particles from the coarse particles to be ready for mixing with Portland cement and water as shown in **Figure 1**.

Portland cement and fine polyethylene waste are mixed by water to get concrete mix without using sand to study the effect of replacement sand by fine polyethylene waste. Different percentages of fine polyethylene waste are used to produce plastic cement. The ranges of polyethylene used are 15, 20, 25, 30, 35, 40, 50, 60 and 80% of the mixing materials with fixed water content of 25% [10].

Portland cement and fine polyethylene waste are mixed with water to get a homogeneous concrete to cast on the small mould. Samples are left in the mould until dry and then are immersed in water for 3–4 days for solidifying and curing to increase their cohesion. After that, samples are taken out from water to dry and their properties are tested. The second step is to immerse these samples again in water for 7 and 28 days to study their stability and the effect of water on their properties.

5.1.2. Results and discussion

Polyethylene is a semi-crystalline material with excellent chemical resistance, good corrosion resistance, and good fatigue and wear resistance. It provides good resistance to organic

Figure 1. Polyethylene waste after cutting and grinding [10].

solvents and strength with low moisture absorption. Moreover, it is a lightweight material, non-toxic material, resistance to stain and offers excellent impact resistance and high tensile strength.

The shape of wet plastic cement is produced by mixing and casting materials without using any vibration or press. The products have a good shape and of light density, which are dependent on the percentage of fine polyethylene waste. The density of plastic cement that is produced in this research lies in the range of 1.972–1.375 gm/cm^3. It is 1.375 gm/cm^3 when the percentage of polyethylene equals 60% [10].

The moisture of plastic cement that is produced in this research was measured after immersing for 7 and 28 days in water. The results show that after 28 days the moisture percentage will be less than the moisture of plastic cement that was immerged for 7 days. The range of moisture after immersing for 7 days is 23.4–10.5% and after immersing for 28 days is 11.6–3.60%. The lower percentage of moisture is equal to 3.60 and 3.79%, which has been obtained when the percentage of fine polyethylene in mixing concrete equals 25 and 30% with immerged time equal to 28 days. Plastic cement with waste polyethylene up to 60% has a good workability because it is possible to make hole by using a drill machine as shown in **Figure 2**.

Plastic cement has a good compressive strength and yield strength. Yield points for different specimens have been found which lie in the range of 568–971 N after 7 days and from 571 to 2352 N after 28 days. It is dependent on the percentage of fine polyethylene waste as shown in some examples in **Figures 3** and **4**. By increasing the plastic waste ratio, the compressive strength values of waste plastic cement decrease at each curing age. This trend can be attributed to the decrease in adhesive strength between the surface of the waste plastic and the cement paste. It seems that the bonding between the plastic particles and the cement paste is weak [10].

It was found that there is a possibility of producing plastic cement from the waste of polyethylene materials that generated from human activities like food packages or crates. The density of produced plastic cement depends on the percentage of waste polyethylene in the concrete mix design. It increased with increasing percentage of waste up to 30% and then decreased gradually. The maximum density of product is 1.972 gm/cm^3, which is less than the density of cement mortar that produced from sand and Portland cement. The density of plastic cement that was produced by using high-density polyethylene waste materials was reduced with 15% of traditional concrete. In addition, the moisture of plastic cement lies in the range of 10.5–23.4% for products immerged 7 days in water. However, for products

Figure 2. Sample of plastic cement produced in this research with a hole [10].

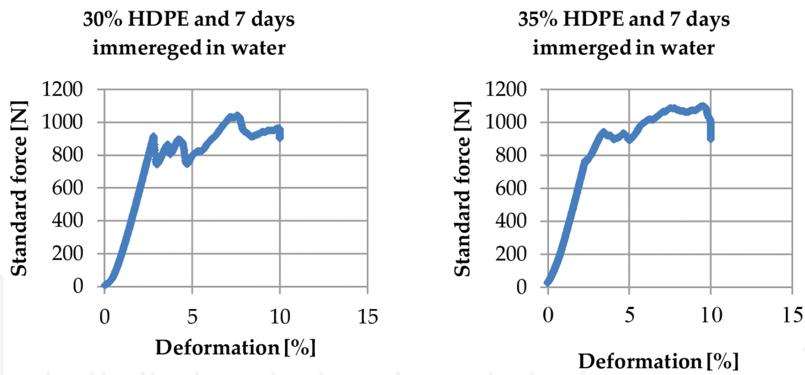

Figure 3. Compressive strength of produced plastic cement with 30% HDPE and 35% HDPE after immerging for 7 days in water [10].

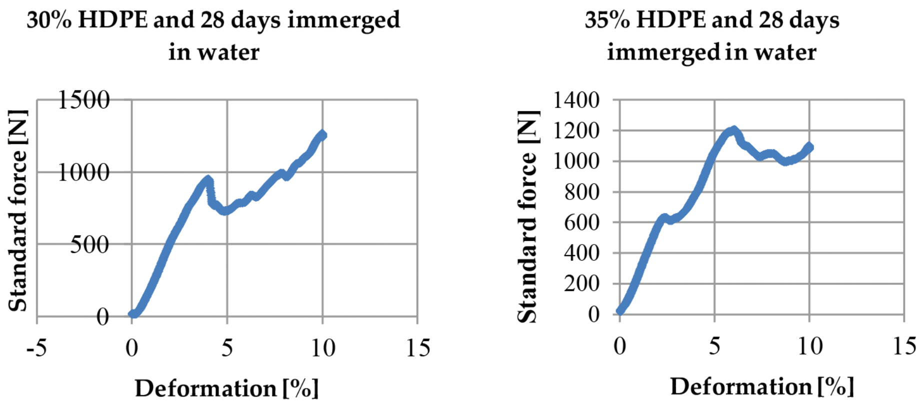

Figure 4. Compressive strength of produced plastic cement with 30% HDPE and 35% HDPE after immerging for 28 days in water [10].

immerged 28 days, the moisture was decreased to be in the range of 3.6–11.6%. The best moisture percentage for products is 3.6 and 3.79% for products with 25 and 30% waste polyethylene, respectively [10].

The best compressive strength for a product was found in the mixture to be 25, 30, and 35% polyethylene. The yield points for them are 971, 915 and 945 N, for immerged 7 days, respectively, and 2352 for mixed of 25% and 1271 N 30% after immerged 28 days. The stress-strain behavior is plastic behavior, which has several stages of deformation. It works as semi-crystalline polymer, flexible concrete and not brittle as Sand-Portland cement concrete. Therefore, their stress-strain diagram exhibited both elastic and plastic deformation before fracture. Moreover, the products with 25–30% waste polyethylene have good workability to make holes without any problem. However, when the percentage of waste decreases or increases, the workability will be weak and power was generated during the cutting operation [10].

Solid-state recycling process becomes an effective and powerful methodology to realize the green state forming from recyclable wastes to useful parts. The developed process can be considered as a typical green forming or environmentally manufacturing process for lightweight materials. It has many benefits including simple, cost and energy saving, and clean recycling because it does not harm the environment. From the above information, it was found that the best and suitable percentage of waste polyethylene is 25–35%, which gives good properties of mixture [10].

5.2. Recycling of non-ferrous metal waste

One of the most important processes that use to eliminate waste, cost, and energy required for recycling non-ferrous metal waste is solid-state metal conversion process that belongs to sustainable manufacturing process. It is a promising technology to eliminate remelting and casting process due to its ability to produce solid parts directly from solid state without remelting, reducing the waste and cost [19].

Different types and sizes of chips were generated during manufacturing operation like turning, milling, and sawing. These chips are accumulated in the workshops and factories which need to be removed and remelted to cast as a useful part. The traditional recycling process becomes costly because it is required by a high number of employees and consumed high energy as well as generated high emission and pollution which are the main challenging task worldwide [19, 20].

The idea of recycling waste is to eliminate and reduce the usage of primary material resources and reduce energy consumption. The traditional recycling methods consume high energy and generated waste again. The amount of waste generated from casting metal can be estimated as 3–5% of casting weight, which is produced as chips again. The energy required to produce 1 ton of primary aluminum is 200 GJ and for remelting aluminum scrap is 10 GJ per ton. In addition, it is difficult to recycle metal chips due to their elongated spiral shape, small size, and surface contamination. Therefore, it's very important to develop an efficient recycling process that prevents generation of chips again. For that reason, sustainable policy becomes the focus for modern industrial societies to reduce the usage of primary resource, pollution control and prevention [19–21].

Nowadays, several recycling methods have been used to transfer chips into useful part which can be classified as conventional and non-conventional recycling method. In conventional recycling method, there is no improvement of mechanical properties and large slag will generate from remelting process and solidification [25]. In addition, 20% of materials will be lost during remelting process, which cannot be avoided. Conversely, in case of thin chips, losses can reach to 50%; therefore, energy consumption and cost of labor will increase as well as the expenditure on environmental protection will increase too. However, non-conventional recycling process was done by extrusion and sintering process, which leads to save 95% of energy that was consumed in conventional recycling process and can reduce solid waste disposal, and CO_2 emission as well. Direct conversion method is one of the non-conventional recycling methods that are relatively simple, economic, and environmental-friendly process, which can be considered as a sustainable manufacturing process [19–24].

Recently, solid-state recycling method of non-ferrous metals like aluminum, copper, zinc, and their alloy chips has been introduced without the melting process to overcome the disadvantages of conventional method [25, 26]. Therefore, scientists have discovered new types of engineering that include sustainable engineering and green engineering that are used to minimize adverse impact and maximize the benefit to economic, social and environmental [19, 27].

In this work, solid-state recycling process was implemented to realize the direct recycling of aluminum-zinc alloy chips and copper metal chips as the green- or sustainable-forming technology. It is used to produce solid part directly from solid state without melting.

5.2.1. Produce solid part metal chips without melting

Al-Zn alloy and copper metal chips that are generated through cutting or manufacturing processes have been used to recycle by using direct conversion method. Chips were cold pressed with a load of 10, 20, and 30 tons and then extruded to produce shaft with a diameter of 12 mm. A significant deformation process was produced that leads to achieve proper material bonding.

Different sizes and shapes of Al-Zn alloy and copper metal chips are collected from the workshop as a waste of cutting operation, which sieve with a mesh between 0.300 and 3.00 mm as shown in **Figure 5**. They were mixed to produce 70% of chips in the size of 1–3 mm and 30% less than 1 mm. The length of chips was up to 11.85 mm and the width in the range of 0.39–3 mm. These chips were compacted and extruded directly without remelting or heating. The pressing was applied from one side and two sides in the opposite direction.

5.2.2. Results and discussion

The results show high possibility to produce solid parts directly from solid chips without any melting and rolling process. The developing process can be considered as a typical green-forming or environmental manufacturing process for lightweight alloys. It saves money because there is no need to prepare powder for forming and sintering the products as the process used for powder metallurgy. The magnitude and direction of pressing significantly affected the properties of produced parts.

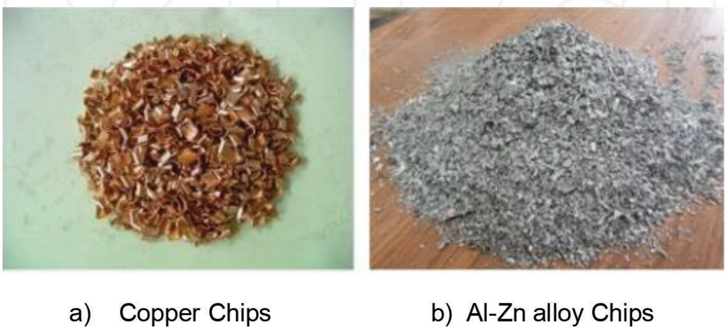

Figure 5. Chips of copper and Al-Zn alloy [19].

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The experimental works show that higher cold-pressing pressure leads to higher density of cold-pressed samples and higher hardness. In addition, pressing from two sides is better than one side because uniform distribution will be obtained with high homogeneity product. The produced parts have approximately the same hardness and density everywhere as same as the standard parts. The pressing from one side leads to produce brittle and incoherent parts. However, pressing from two sides produced strong and coherent parts with density and hardness close to original parts as received as shown in **Figure 6**. Moreover, the result shows that the smaller and simpler chips are better input materials for cold compression; otherwise, there is a need to heat chips before or during pressing process.

Figure 6. Samples of shafts produced from Al-Zn alloy and copper chips [19].

The density of cold extruded Al-Zn alloy and copper metal chips reached 95% of the density of parts produced by conventional method. In addition, the hardness of cold extruded chips was equal to 98% of the parts produced by cast and rolled [18, 28–30]. The result that was obtained in this research agreed with the result that was obtained by Chiba et al., which found that cold extruded chips were 97% of cast materials [29, 31]. Therefore, direct recycling method or solid-state recycling method is a promising approach technology that helps to overcome the problem of material loss during remelting of chips and energy saving with environmental protection by reducing gas emission.

Solid-state recycling process becomes an effective and powerful methodology to realize the green state forming from recyclable wastes to useful parts. The developed process can be considered as clean recycling technology and typical green-forming or environmentally manufacturing process for lightweight alloy. There is no need to prepare powders for forming and sintering the products.

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INTECH

Sustainable Power Technology: A Viable Sustainable Energy Solution

Kikelomo Ijagbemi

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Abstract

There is no doubt that power reliability in most nations of the world has increased. Over the years, electric power has grown beyond providing utilities to being a dominant and fundamental part of civilization with smart phones, electronic vehicles, personal computers, etc. In order to meet the power demands of a growing economy, energy losses need to be minimized along transmission and distribution lines from power generation to the final load. This chapter discusses renewable energy sustainable solutions and superconducting power applications as a possible solution for energy sustainability, the environmental impacts of sustainable and superconducting technology with their future trends. It introduces smart grid and its roles in sustainability.

Keywords: superconductivity, power technology, sustainable energy

1. Introduction

Superconducting power technology offers the possibility of transmitting and distributing power with zero resistance through the adoption of a cooling method known as the cryogenics. Superconducting cables and many other applications use materials called "High Temperature Superconductors (HTS)" or Low-Temperature Superconductors (LTS). This chapter focuses more on HTS applications, which uses environmental friendly liquid nitrogen as the coolant. As shown in **Figure 1**, below the critical parameters: the critical temperature (Tc), the critical field (Hc), and the critical current, superconducting; this in turn makes the power density very high, and losses are practically zero. This region below the three constraints is known as the critical surface. Unlike conventional wires, HTS cables operate at a very high current with reduced operating voltage that produces efficient power in the grid.

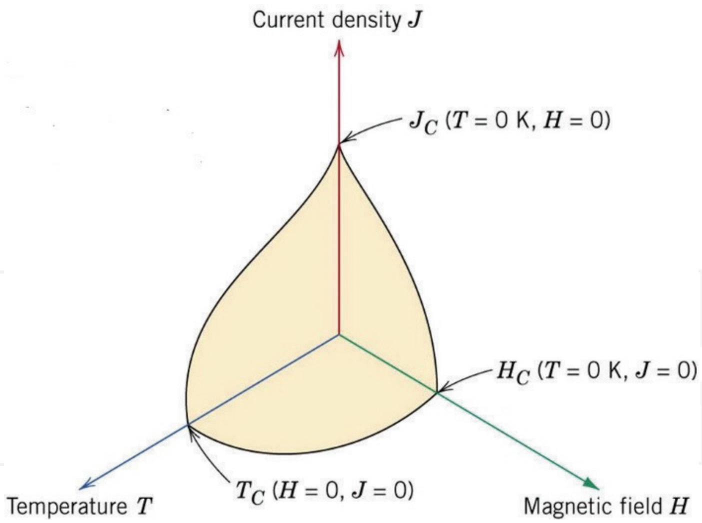

Figure 1. The critical surface of a superconductor [1].

In our society with increasing appetite for various electrical smart gadgets coupled with the high level of industrial production, the power generated has to be efficiently transmitted in order to meet the needs of consumers. The power grid serves as the intermediary network between the power generation plants and consumers. Power reaches its consumer in the following order:

1. Generation
2. High-voltage transmission substation
3. High transmission lines
4. Primary distribution substation
5. Secondary distribution substation
6. Consumers

It was estimated in the United States that power demand will grow from 3.9 billion kWh in 2010 to 4.7 billion kWh in 2035 [2]. This massive load growth poses a challenging overload to conventional aluminum or copper technology; the requirement to minimize inefficiency from overloading can be met by superconducting power technology because it can carry large amounts of power in a small cross-sectional area. **Figure 2** shows the stages of power transmission and distribution. The closed-loop cryogenic application does not support heat loss to the outside environment as compared to conventional systems that have direct

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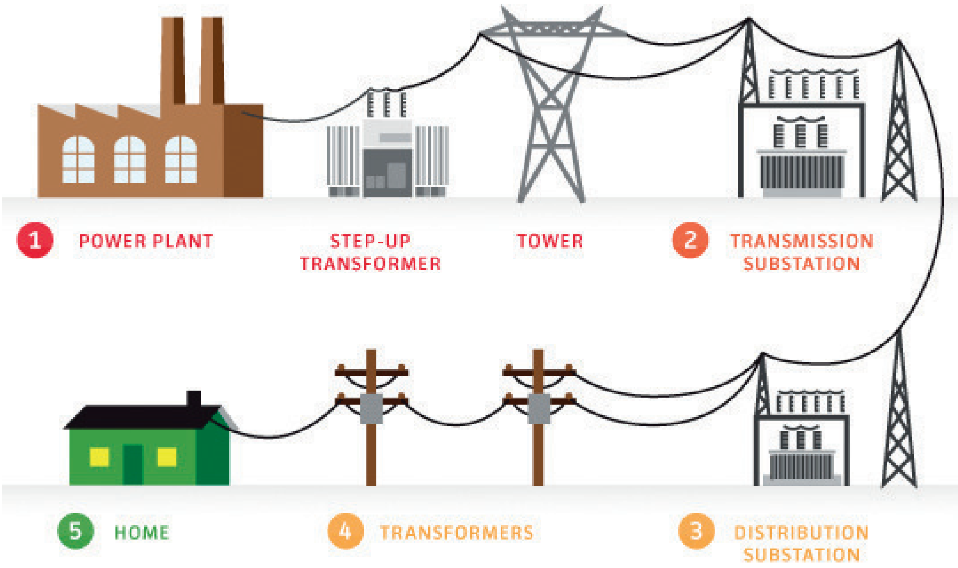

Figure 2. Typical power transmission and distribution [4].

heat loss impact on the environment. Moreover, due to its high energy per unit volume, superconducting applications are light in weight and are compact unlike the heavy conventional systems made of copper [3].

2. Energy sustainability

There are different sources of electrical power energy which are grouped as renewable (the wind, geothermal, solar, and hydropower) and nonrenewable (nuclear, coal, oil, and natural gas) energy sources. Sustainable energy has become a necessity for mankind and has a lot to do with renewable energy sources, which can provide energy for this present generation without wasting the natural resources needed for the future generations. In order to sustain power for the future, many renewable sources such as the wind, solar, hydroelectric, and biomass generation have been explored. This section discusses the various types of renewable energy as sustainable energy sources which are environmentally friendly. Presently, only 23.7% of the global electricity generation comes from renewable sources [5].

2.1. Biomass energy generation

Biomass is gotten from forest residues, wood waste, agricultural residue, and biomass feedstocks. Biomass is regarded as a clean energy because it emits lower carbon dioxide when compared to nonrenewable energy sources. Although the entire biomass power generation cycle is not totally free of CO_2, harvesting and transporting biomass involves biochemical and thermochemical processes that release the biogas and heat, respectively. As of 2010, 4% of the energy used in the United States were from biomass [6].

Biomass continues to be the largest non-hydroelectric renewable technology throughout the forecast horizon, growing from a capacity of about 6.7 GW in 2000 to about 10.4 GW by 2020. Similarly, generation from biomass will grow from 38.0 billion kWh in 2000 to 64.3 billion kWh by 2020 [7]. This means that the need for power generation from biomass alone will increase by about 69.2%.

2.2. Hydroelectric power generation

This being the first-generation renewable energy source, it is the most commercialized renewable energy source. Hydroelectric power is generated through the kinetic energy from the high-speed water made to flow through a dam. The water turbine actuates the speed control and in turn, drives the generator. From **Figure 3**, the large hydroelectric plant is projected to

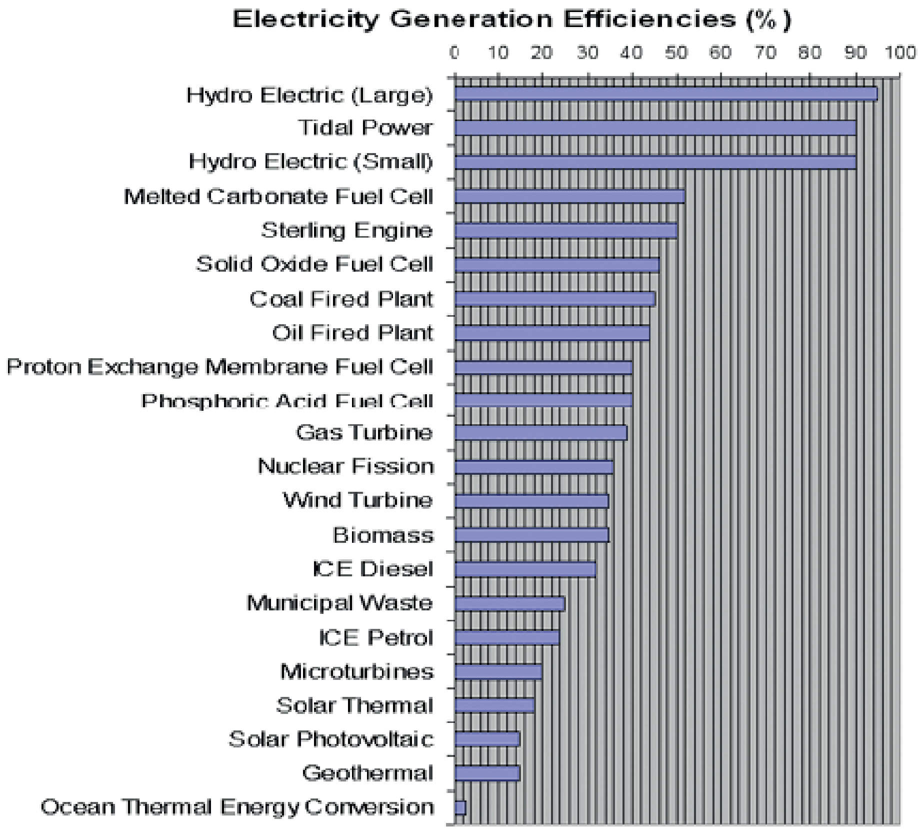

Figure 3. The efficiency of various power plants [8].

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have efficiency as high as 95% in 2020; efficiency is based on the turbine design, wave power, volume of water, and other conversion system limitations.

2.3. Solar energy generation

This is the process of absorbing sunlight to be converted to electricity, and because it does not emit CO_2, it is one of the solutions to minimizing greenhouse gases. The light produced by sunlight is absorbed by solar panels and stored as direct current (DC), before it is converted to alternating current (AC) electricity by an inverter. One of its major disadvantages is that its peak period is during the day and at such, energy needs to be stored during the peak period so energy can be supplied in the off-peak period. PV cells convert solar energy into electrical energy with a conversion efficiency of around 15%.

2.4. Wind energy generation

Wind generation involves the use of wind turbine to convert the movement of air into electrical energy. The movement of air increases with height. Power generated depends on the efficiency of the system, wind speed rotor blade design, capacity of storage systems, and density of air. In a century where environmental pollution has caused great impacts like global warming on our planet, there is the drive to pursue cleaner means of energy like. Considering superconductivity in the power grid, solar energy and wind energy are the most used renewable energy sources.

2.5. Geothermal energy generation

Energy generated from heat in the Earth is referred to as geothermal energy. This energy is readily available as it can be found in different corners of our environment, be it at the dump stand or at the top of the mountains. This energy is one of the clean and sustainable solutions to the dependency on fossil. As shown in **Figure 4**, the United States in 2015 produced 15,918 thousand MW with a state like California, which has 7% of the state's electricity generated exothermally. One of the major resources of geothermal energy is below the Earth's crust, where there is a constant heat layer known as the hot molten rock or magma. This layer has the highest underground temperature with seismically active regions that allow heat to pass through tectonic plate boundaries. There are about three basic designs for geothermal plant, but the simplest is the dry steam generation. This concept involves getting the steam from the hot layer into the turbine, and then a condenser turns the hot steam into water that controls the turbine. The turbine in turn drives the generator which generates power. Unlike wind and solar energy, geothermal energy is found all through the year; it is not a seasonal renewable energy source [9]. Geothermal power costs 3.6 cents/kWh as compared to 5.5 cents/kWh for coal [10].

3. Applications of superconductivity in the power grid

Based on the existing infrastructure, superconducting technology has made reasonable headway into the electrical power transmission and some part of its distribution, but the downside

	Generation at Utility Scale Facilities									
Period	Wind	Solar Photovoltaic	Solar Thermal	Wood and Wood-Derived Fuels	Landfill Gas	Biogenic Municipal Solid Waste	Other Waste Biomass	Geothermal	Conventional Hydroelectric	Total Renewable Generation at Utility Scale Facilities
Annual Totals										
2007	34,450	16	596	39,014	6,158	8,304	2,063	14,637	247,510	352,747
2008	55,363	76	788	37,300	7,156	8,097	2,481	14,840	254,831	380,932
2009	73,886	157	735	36,050	7,924	8,058	2,461	15,009	273,445	417,724
2010	94,652	423	789	37,172	8,377	7,927	2,613	15,219	260,203	427,376
2011	120,177	1,012	806	37,449	9,044	7,354	2,824	15,316	319,355	513,336
2012	140,822	3,451	876	37,799	9,803	7,320	2,700	15,562	276,240	494,573
2013	167,840	8,121	915	40,028	10,658	7,186	2,986	15,775	268,565	522,073
2014	181,655	15,250	2,441	42,340	11,220	7,228	3,202	15,877	259,367	538,579
2015	190,719	21,666	3,227	41,929	11,291	7,211	3,201	15,918	249,080	544,241
2016	226,872	33,367	3,388	40,504	11,562	7,375	3,131	17,417	265,829	609,445

Figure 4. Net generation of renewable energy sources from 2006 to 2015 in the United States [11]. Annual totals are in thousand MW.

to this technology is that its cryogenic cooling requirement makes it expensive when compared to conventional technologies. Therefore, utility companies have not adopted the technology yet.

Superconductivity applications such as superconducting generators and motors, superconducting fault current limiters, superconducting transformers, and superconducting magnetic energy storage systems all find their usefulness in the power grid. These systems are compact and energy efficient. The major drawback of superconducting technology is the cost of maintaining its cryogenic systems. **Figure 5** shows the response of electrical resistance against temperature in High Temperature Superconductors (HTS) and Low Temperature Superconductors (LTS). LTS operate at low temperature (about 4K) in liquid helium, and they require little energy to quench.

HTS are superconductors with high-temperature margin and heat capacity which is responsible for its high stability margin. Prior to 1986, the highest critical temperature of a superconductor was 23.2 K until Bednorz and Müller measured a critical temperature of about 30 K in La_2CuO_4 La_2CuO_4. Examples of high-temperature superconductors are $Bi_2Sr_2CaCu_2O_x$ (Bi-2212), $Bi_2Sr_2Ca_2Cu_3O_x$ (Bi-2223), and $YBa_2Cu_3O_x$ (Y-123). They are usually cooled with liquid Nitrogen at about 77K. They are also known for their large magnetic field >23T, high current density > 300 A/mm^2 and high allowable heat input [12].

3.1. Fault current limiters

The continuous growth in the demand for power necessitates the need for superconducting fault current limiters (SFCL). The bigger the size of the grid, the higher the chances of faults; this affects the operation of power equipment like transformers and other machines in the grid. A fault condition reduces the efficiency of the system, and this may cause a power outage if not promptly addressed. Moreover, the standardization of this technology is still immature, and due to cost issues, its marketability is very low, but this is not to underestimate its significant benefits.

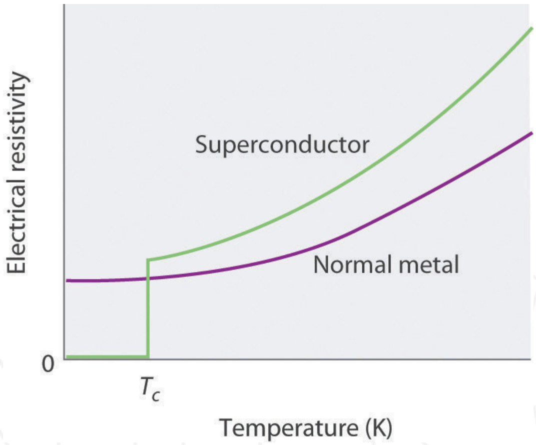

Figure 5. Plot of electrical resistance against temperature [13].

There are several types of SFCL designs, but the basic design works by applying the superconductivity principle as a means of protection. It basically has the superconducting material connected in parallel with a shunt, more resistive in the superconducting state but less resistive in the normal state. The superconductor continues its operation in liquid nitrogen based on its zero resistance until there is a fault condition; when current suddenly rises above its critical current, the excess current flows through the shunt metal after which the superconductor recovers its superconductivity back. SFCL employs its physical characteristic by handling the fault condition promptly within its first peak as shown in **Figure 6**.

One of the highlights of superconducting FCL is that they can protect upstream subnetworks, that is, they can protect both transmission and distribution network in a system. It is more suitable for these applications because nonsuperconducting FCL needs to have a predetermined position in order to protect subnetworks. This technology cuts out the cost of replacing circuit breakers, transformers, and separation of networks after a fault occurs. These mentioned components become reactive in a fault situation. SFCL increases stability in the transient system; instead of making significant changes like buying a new transformer or changing the circuit breaker when there is increased magnitude, SFCL protects the grid as subnetworks can be connected.

Furukawa Electric Cable (FEC) speculates that in the future, SFCL will be one of the power devices that permits a large number of renewable energy generators and avoids the risk of a network accident such as a ground fault and a circuit fault in a complex and huge power network [14]. Within the past decade, in Baiyin, Gansu province of China, a 10 kV/1.5 kA SFCL was integrated into the grid alongside with 630 kVA/10 kV/0.4 kV HTS transformer, 380 V/1.5 kA HTS AC cable of 75 m length and 1 MJ/0.5 MVA SMES [15]. In the future, continuous researches are ongoing on the improvement of SFCL and its application in the power grid especially its renewable energy applications, where SFCL will act as a protection for the network (**Figure 8**).

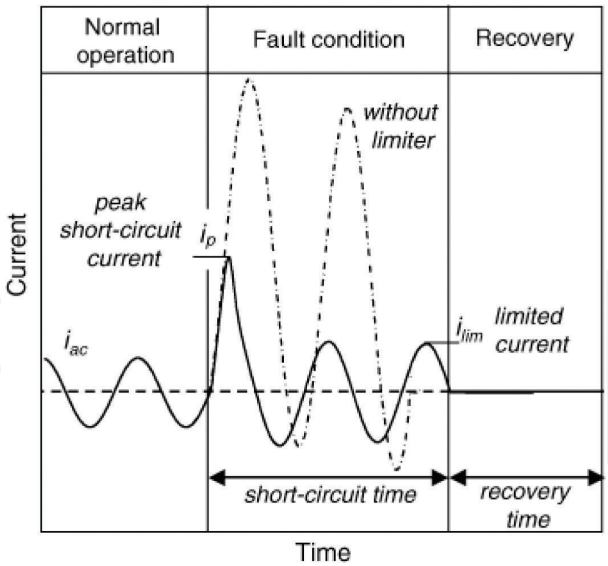

Figure 6. Plot showing how an SFCL works [16].

3.2. Superconducting magnetic storage energy systems (SMES)

Considering sustainable energy sources, there is a need to store the energy generated especially during peak periods, when most conditions at the renewable generating plant are favorable. SMES stores large energy in DC form as magnetic energy which is cycled indefinitely by the current flowing through the superconductor. SMES has power converter systems that convert DC to AC suitable for delivery to the utility bus as this makes it more reliable than other storage devices. For the purpose of superconductivity, the choice of inductors is chosen because the higher the current or the inductance, the more energy is stored. From Eq. (1), the entire volume integral is taken, because the number of turns of the inductor affects the energy:

$$E = \frac{1}{2\mu_0}\int B^2\,dv \tag{1}$$

A SMES system consists of four parts, which are the superconducting magnet (SCM), the power conditioning system (PCS), the cryogenic system (CS), and the control unit (CU) [17]. The first superconducting SMES application operating in a grid in the United States was a flexible AC transmission system [18]. The Bonneville Power Administration used a 30 MJ SMES in the 1980s. This SMES was operated for over 1200 h of energy transfers equivalent to 1 megacycle. One of the commonly adopted topologies of the SMES is the voltage source converter (VSC) shown in **Figure 7**, which is chosen based on its ability to control real and reactive power [19, 20]. This ability is a great tool used for reducing power fluctuations in renewable energy generation; hence, it is a more stable system. SMES are environmentally friendly, unlike batteries which depend on a chemical reaction and can act as a backup power supplier in case there is power loss from the main power supply (**Figure 7**).

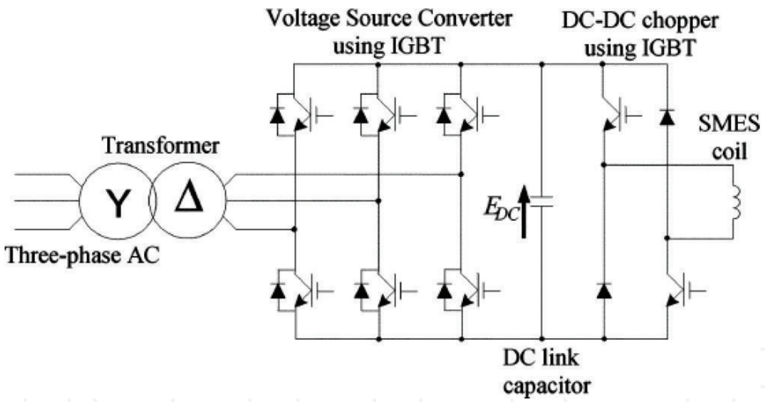

Figure 7. Schematic of a VSC SMES [21].

3.3. HTS cable

These are power cables that transmit power at lower transmission loss. There are two types of HTS cables, the direct current (DC) cable and alternating current (AC) cable. Discussing HTS Cable shown in **Figure 8**, this cable has the copper core that allows the flow of excess current in case there is a fault; the HTS tape is the superconducting layer; the high-voltage dielectric acts as an insulator, HTS shield tape, and copper shield wire; liquid nitrogen coolant flows within the inner cryostat wall and cools down the temperature below critical temperature; and the outer protective layer protects the entire assembly. Comparing HTS AC cables to conventional copper cables as discussed in [3], HTS cables can carry about 2–4 kA as Root Mean Square (RMS) voltage within the same cross section that carries 1 kA in copper. HTS cable design has current limiting capabilities. This encourages safe links between two more subnetworks in the grid in order to provide an alternative means of power supply in a power failure situation. HTS cables are light in weight and have increased capacitive charging length due to its high-line charging current.

At high frequencies AC cables are prone to AC losses generated by the power source and converters; this is the reason why superconducting DC cables improve the efficiency of electricity transmission and distribution network. Superconducting DC cables have four major parts (a) the voltage insulation, (b) the HTS superconducting tape, (c) the cryogenic envelope, and (d) the cooling fluid [22]. Other special advantages of high-voltage DC (HVDC) cables are its non-electromagnetic radiation capabilities, its compact design, and the absence of heat emission to the environment. This cable is suitable for a wind farm and photovoltaic power generation that requires the transmission of DC. In the future, DC cables can help in resolving the densely loaded power grid in urban regions.

4. Environment impact

Predominant challenges of the power sector are load growth, environmental safety, power quality, and reliability. Some of the challenges of renewable energy sources are:

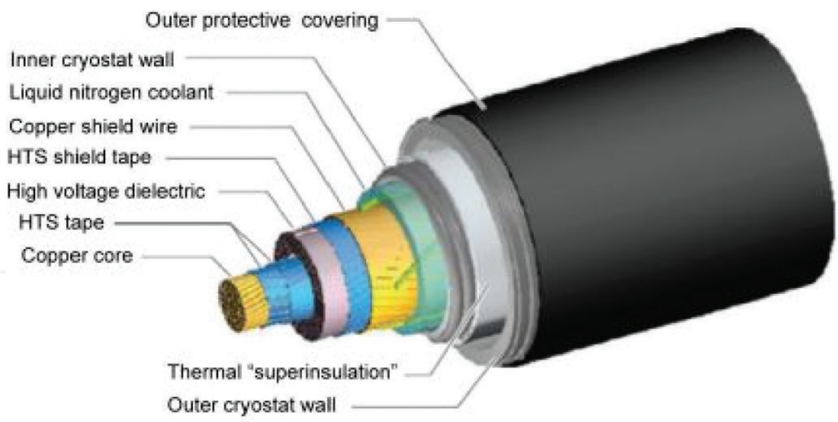

Figure 8. Cross section of an HTS AC single-core cable [23].

1. Its variance in energy production with time as renewable energy sources vary with seasons which is the reason why they have peak periods and low peak periods.
2. Its storm damage can be very destructive especially when the design is not strong enough to withstand at the level of storm.
3. The continuous availability of biomass for energy indirectly affects the richness of soil needed.
4. Most renewable energy sources produce DC which is the reason why superconducting DC cables are recommended for the future transmission. In order to use this energy in an AC grid, additional cost for SMES or inverters will be incurred.

4.1. Impact of renewable energy sources

In the United States, for aviation safety, Federal Aviation Administration (FAA) requires that wind generators should not be above 200 ft tall. In the US, the National Renewable Energy Laboratory carried out a survey of large wind facilities showing that between 30 and 141 acres/MW of power output capacity is used for large wind facilities. Moreover, less than 1 acre/MW are affected permanently, and less than 3.5 acres/MW are temporarily affected during construction [24]. The development of the wind energy generation site interrupts other biological activities in that environment. The unused part of the land at a generation site can serve other purposes like agriculture. Research has also shown that when wind speed is low, bats are more active; the change in air pressure around wind turbines has led some bat fatality. In order to reduce the fatality rate, wind turbine can be kept motionless at low speed [25].

Solar power land area requirements vary depending on the technology, the topography of the site, and the intensity of the solar resource. Land use for utility-scale PV systems ranges from

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3.5 to 10 acres/MW. The unused portion of the land at a solar generation site cannot be used for other purposes due to the orientation of the photovoltaic cells. Solar energy generation in itself is a clean energy process, but the entire life cycle especially manufacturing and disposal processes contributes to global warming emission at a rate of 0.08–0.2 pounds of carbon dioxide/kWh which is still lower as compared to fossil foil power sources [26].

Hydropower generation has an extreme impact on ecology if its generation process involves flooding the land. Hydroelectric power from dams can result in the fatality of fishes if they come in contact with the turbine blades. Releasing of water periodically can also harm plants and animals downstream. The entire life cycle of hydropower generation is dependent on the region and generating plant, but it is estimated to be about 0.5 pounds of carbon dioxide/kWh [27].

4.2. Impact of superconductor applications

The following are the impact superconductivity on the environment:

1. Reduced right-of-way disruption makes it easily installed underground to avoid messing up urban cities with wires.
2. Lower voltage operation makes it less harmful to living things.
3. There is no electromagnetic radiation to the environment.
4. No heat emission to the environment.

4.3. Impact of smart grid on energy sustainability

Most existing utility grid is one way in direction; it lacks information about the system state and the load. Also, it involves the operator's discretion to detect faults. Smart grid is the grid of the future because:

1. It is intelligent.
2. It involves two-way communication between the load (consumer) and the utility company.
3. It has sensors.
4. It is remote checked and has pervasive control.
5. It is self-healing and attacks resistance.
6. It gives consumers control.

Smart grid accommodates dynamism in the grid as it optimizes the use of its capital assets while reducing maintenance or operational cost.

5. Conclusion

In order to reduce the use of fossil fuel and reduce greenhouse gases in the future, it is proposed that renewable power sources be adopted. However, the introduction of new grid components may introduce fluctuations and instability to the grid. Superconducting power applications coupled with smart grid feature is the most promising solution for grid adjustments in the future as they are more reliable and ensure stability in the grid. Sustainable culture and skill need to be developed and maintained amidst citizens to reduce further power demand. More network installation should be carried out to review realistic situations, and more researches regarding reducing cryogenic cost are ongoing so that superconducting technology becomes marketable and less expensive.

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Chapter 3

Sustainable Maintenance Practices and Skills for Competitive Production System

Adeyeri Michael Kanisuru

Additional information is available at the end of the chapter

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Abstract

Many industries are becoming moribund, while those who are in operatives are producing at low efficiency which are not commensurate to the resources invested. These imbalances and poor performance attest to the fact that the maintenance practices adopted were unskilfully implemented and are not sustainable. Therefore, this chapter discusses the maintenance strategies and skills needed in establishing a sustainable maintenance technology for the manufacturing industries by the formulation of sustainable maintenance framework practices for competitive production systems and translation of the formulated framework to iconic and equation models. The expected outcome showed that maintenance sustainable practices cannot be undermined if production set goals and overall equipment effectiveness are to be achieved. Successful implementation of this instructive methodology will reduce wastages, eliminate machine downtime, increase machines performance with improved functionality of parts thereby providing maximum usability and reusability of parts/components and thus increase the machine optimal functionality and efficiency.

Keywords: sustainability, maintenance skills and practices, competition, production systems, models

1. Introduction

Production losses are incurred when machinery failures and breakdowns become erratic and unattended to as required and expected. Man-hour and production time are no longer optimized and maximized as mean time between failure and mean time to repair decreases and increases, respectively. The consequence of this frequent failure has not only led to losses but also affected compromise of standards, product dimensions and products' integrity.

In general, the goal of maintenance is to eliminate or to avoid unnecessary or unplanned downtime due to failure. Maintenance activities can influence the entire manufacturing/production operation, from product quality to on-time delivery records and its effect on the environment. Good maintenance practices can cut production costs immensely, whereas poor maintenance procedures can cost a company millions of dollars to effect repairs and correct poor quality and production lost. In the bid to correct and reduce this menace, a good sustainable maintenance strategy and practice needs to be adopted. This assertion may lead to the question of asking 'why sustainable maintenance practices and not just maintenance practice?'

According to Jawahir [1], Sustainability is '*meeting the needs of present without compromising the ability of future generations to meet their own needs*'. In a more elaborate form, by application and implication, *sustainable maintenance practices are practices of high quality aimed at increasing machines performance with improved/enhanced functionality of parts using safe, secure technologies and methods utilizing optimal resources by reducing or eliminating machine downtime, mean time to repair* (*MTTR*) *and products' wastes thereby providing maximum usability and reusability of parts/components, enhanced production benefits, economic impact and making the enterprise to stand competitively*. No maintenance method will work better for any manufacturing sector if such manufacturing set-up has not been fully studied and analysed. It is beyond being a formula, but rather, it calls for relationship in knowing what is required for respective industries.

Having established the definition of sustainable maintenance, there is need to discuss the elements of sustainable maintenance practices, skills and strategies (and this is showcased in Section 1.1). Section 1.2 discusses the various maintenance strategies that are practicable, whereas selection guidelines for sustainable monitoring programme for machinery are discussed in Section 1.3. Maintenance model formulation for different manufacturing methods at varying competitive environment is being addressed in Section 1.4. Sections 1.5–1.7 explain the steps for improving sustainable maintenance plan, the skills required by 'maintenance engineer to be' in maintaining sustainability objectives and conclusion, respectively.

1.1. Elements of sustainable maintenance practices

The elements of sustainable maintenance practices are shown in **Figure 1**. They are divided into two groups. The four factors painted in green colour, namely: machine records keeping; diagnostic techniques; prognostic techniques; and machine condition monitoring techniques are the tooling dependent factors. Whereas the three factors painted in orange colour, namely: environmental impact; machines functionality; and manufacturability are the informative factors whose parameters and information are needed by dependent factors to provide decision and direction on actions needed to be taken on machinery to effect maintenance activity.

Mathematically, if sustainable maintenance practice is tagged with acronym (SMP), then the connecting equation expressing the SMP is given in Eq. (1)

$$\mathrm{SMP} = F(M, D, P, C, F, M, E) \tag{1}$$

where M is the machine records keeping, D is diagnostic technique, P stands for prognostic technique and C is the machine condition monitoring technology. F, M and E are acronyms

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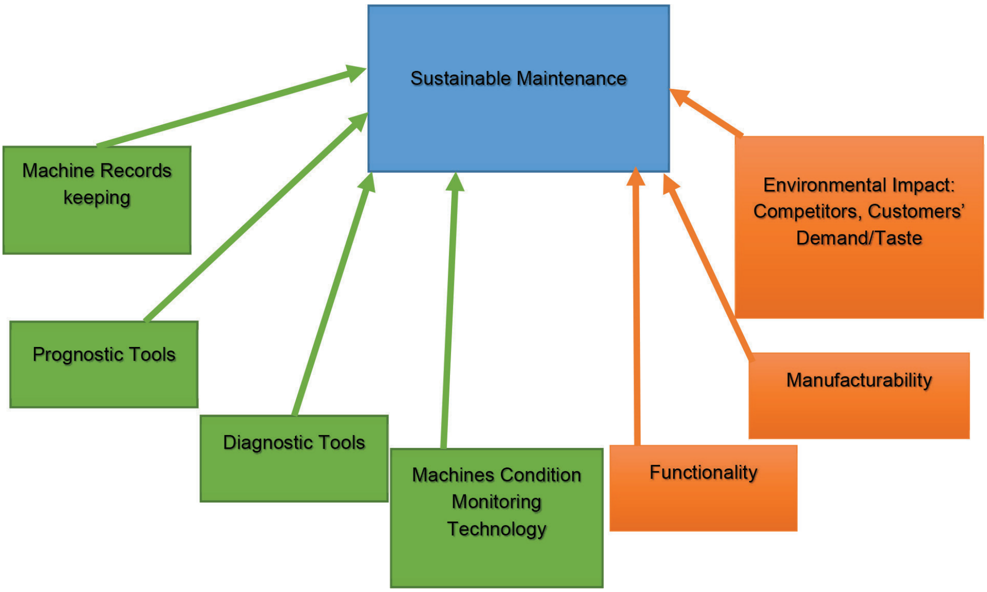

Figure 1. The elements of sustainable maintenance practices.

for machines functionality, manufacturability and environmental impact, respectively. These factors are as explained in the preceding subheadings. The four factors in green boxes are inherent and internal factors associated with data keeping, whereas the other three factors in orange boxes are external factors imposed on the machines due to demand pressure and rivalry competitions that may arise in the course of production which will in one way or the other affect the machinery functionalities.

Machine records keeping: This is a sine qua non to sustainable maintenance practices. The documentation of every activity on machinery and their components will form the knowledge base to determine the performance behaviour, prediction of machine signature and other necessary attentions that are ought to be given to them.

The three machine records keeping approaches to look at in this chapter are preventive maintenance visit check time schedule; maintenance log book and repair report. These three samples, which are explicit to understand, are shown in **Tables 1**, **2** and **3**, respectively.

Prognostic tools: These are the tools meant to predict the future performance of components by assessing the extent of deviation or degradation of a system from its expected normal operating conditions. Its principle is based on the analysis of failure modes, detection of early signs of wear and ageing and fault conditions. It is more effective if the knowledge of the failure pattern that leads to system deterioration is trended. The prognostic approaches are model based built on collected or retrieved data from machines at both good and deteriorated condition. Its formulation is characterized by: varying of loading conditions in haphazard manner and monitoring of machine faults through preset time for defining its behavioural path. The concept in general aids in the estimation of remaining useful life (RUL) of the machine [3].

Name of components	Periods of activities carried out (weeks)								
	1	2	3	4	5	6	7	8	9
Electric Motor-1	ABL	ABL	ABCL	ABL	ABL	ABCL	ABL	ABL	ABCL
Belt 1	A	A	A	A	A	A	A	A	A
Belt 2	A	A	A	A	A	A	A	A	A
Gearbox-1	ABL	ABDL	ABL	ABL	ABDL	ABL	ABL	ABDL	ABL
Bearings	AB	AB	AB	AB	AB	AB	AB	AB	AB
Crusher plates	AW	ABW	AB	ABCW	ABC	ABC	ABC	ABC	AB

A = visual check, D = lubrication analysis, B = temperature check, L = lubrication check only, C = vibration check, W = wear check.

Table 1. Example of a simple preventive maintenance schedule.

GEAR DRIVE MAINTENANCE LOG

Location: Ground floor	**Machine:** Milling Machine I
Gear drive type: Reducer 1:10	**Serial no.:** xxxxxxxxxxx
Date of putting in operation: 20/4/2015	**Manufacturer:** Tokyo
Special maintenance requirements: Oil Grade 05	**Auxiliary drives:** ☐ Belts __________ ☐ Chain __________ ☒ Coupling **Flexible Coupling** ☐ Others __________

Date of Activities	Levels of Activities										
	Add Oil	Change Oil	Temp. Check	Vibr. Check	Lubri Analy-Sis	Load Check	Aux. Drive Check	Change Seal	Change Bearing	Complete Overhaul	Remark/ Recommendation
1/6/16	Yes	No	86 °C	No	No	46 A	Yes	No	No	No	Gear belt was Tensioned
12/6/16	No	NO	89 °C	No	Yes	48 A	Yes	No	No	No	Oil is due for changing next week
19/6/16	No	Yes	92 °C	No	No	50 A	Yes	No	No	No	Gear box oil was changed with Grade 05
26/6/16	No	No	85 °C	510	No	45 A	Yes	No	No	No	Perfect

Source: [2].

Table 2. Example of simple 'Maintenance Log'.

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GEAR DRIVE REPAIR REPORT					
Location:	**Building 345, Ground Floor**		**Machine:**	**Textile mill # 4**	
Gear drive type:	**Reducer 1:10**		**Serial no.:**	xxxxxxxxxx	
Date of putting in operation:	**5/21/2004**		**Manufacturer:**	**Japan**	
Date of Repair:	**5/26/2008**		**Auxiliary drives:**		
Special maintenance requirements:			☐ Belts		
Oil Grade 05			☐ Chain		
			☒ Coupling	**Flexible Coupling**	
			☐ Others		
Part	**Failure Description**	**Mark**	**Part**	**Failure Description**	**Mark**
Auxiliary Drive	Chain or belt broken		**Gears**	Seal worn out	+
	Sprocket/Pulley worn out			Broken teeth	
	Keyway problem	+		Worn out teeth	+
	Drive shaft bent			Others	
	Coupling damaged		**Lubrication**	No oil	
	Coupling rubber broken	+		Little oil	+
	Others			Dirty oil	
Sealing	Lip seal defective	+		Water in oil	+
	Housing seal defective	+		Breather defective	
	Others			Others	
Shaft	Seat of bearing worn out		**Housing**	Cracked	
	Seat of Lip seal worn out	+		Problem with bolt connection	+
	Bent or broken			Problem with pin connection	+
	Others			Others	
Bearings	Worn out	+	**Base Plate**	Loose, weak	+
	Excessive damaged			Problem with bolt connection	
	Others			Problem with foundation	+

Source: [2].

Table 3. Example of simple 'Repair Report'.

Diagnostic tools: Diagnostics is required when fault prediction of prognostics fails and a fault occurs. It addresses fault detection, isolation and its identification when it occurs. To detect faulty components or machines, it calls for knowing what is going wrong in the monitored system; fault isolation is a task to locate the component that is faulty; and fault identification is a task that helps in the determining the nature of the fault when it is detected [4]. Diagnostic activities are posterior event analysis, whereas prognostic are prior event analysis.

The basic maintenance diagnostic tools based on the signal time series and time series analysis theory are machinery data acquisition, data processing, maintenance decision making, pseudo-phase portrait, singular spectrum analysis, wavelet transform and correlation dimension [4].

Machines condition monitoring technology: A condition monitoring program can be used to do diagnostics or prognostics, or both. The condition monitoring technology employs data acquisition on machinery vibration, its acoustic, oil analysis and temperature, pressure, moisture, humidity, weather or environment through the use of versatile sensor-liked equipment attached to the observed components [4]. The detailed description of these condition monitoring tools are as follows:

i. Lubrication monitoring

Lubrication monitoring is a tool for condition monitoring meant to reduce friction and wear between machine component parts with relative motion. Such component parts include gears, bearing and hydraulic systems. The substance used in achieving this is called the lubricant. The use of appropriate or recommended lubricant either by manufacturer or maintenance experts plays a vital role in machinery sustenance. The choice of right lubricant will not only reduce wear from the machine but also convey off wear debris from the component parts if and when it occurs.

ii. Vibration monitoring

This deals with the measurement of vibrations generated in machinery by its dynamic components. On a general note, rotating machinery is characterized by vibration pattern in a repeated manner intermittently. The intermittent or periodic pattern of signal from the machine forms the basis for monitoring because examination can be done on either at off-load or on-load. Therefore, the outcome from the vibration analysis will form or give basic information about the mechanical condition of the machine being monitored.

iii. Thermal monitoring

The need for thermal monitoring arises due to increased temperature that machines do experience at their surface. According to Okah-Avae [5], there are associated faults or flaws that are linked to temperature rise in machinery. Hence, the need for its monitoring. Thermal monitoring technique helps in determining the health and performance probity of machinery. Its measurement and analysis techniques include the use of thermal imaging camera; surface contact sensors (thermistors or thermocouple sensors); radiation sensors (radiation pyrometers) and surface temperature indicators. When suitable sensor is used at either on-load or off-load on the equipment or machine to be monitored, there will be corresponding temperature read out indicating the thermal signature of temperature distribution of the equipment. This outcome will form based on which inference can be drawn about the behaviour of the equipment.

iv. Visual inspection

This is critical appraisal or examination of equipment or machinery either in use or not in use visually. When machines are being used, there is possibility that incipient fault (fault that is not temperature or vibration based) may arise calling for its immediate attention and rectification. Through visual inspection, such faults are being addressed. Example of visual inspection includes routine check-up, machine examination before being used, just to mention a few.

v. Operational dynamics analysis

This is similar to visual inspection, but it is majorly meant to ascertain if design specification matches with equipment supplied or received at the shop floor.

vi. Electrical monitoring

This entails regular checking of electrical parts and components such as main cable of power supply of the machine (to guard against disconnection or partial contact); switches; electric motor (checking against motor flux leakage) and input voltage (confirming if it is in line with recommended voltage), so as ensure operational probity. Other critical issues aimed at correcting under electrical monitoring are identification of poor connection, isolation of faulty isolators and guarding against overloading.

vii. Failure analysis

The underlying principle of machine condition monitoring tools lies on failure determination and how it can be avoided. Failure analysis is based on the processed retrieved data through the use of model and submodel criteria trained to establish why, when and how failed components could be corrected and avoided in the future.

Environmental impact: This is also a factor to be considered when aiming at perfect sustainable maintenance in the midst of competitors. At production, the quantity of product to be produced as output is a function of the number of competitors producing that same singular product as well as the quantity demanded provided the quality of the product produced is constant. As quantity demanded increases, the industry will intend to produce more to meet up with the increasing demand thereby subjecting the machines to more usage. In order for the industry not to lose customers as well as not compromising product's quality, there is need for the machines used for production to be maintained through the use of sustainable maintenance strategy suitable for profit maximization. Therefore, this factor is very significant to machines maintenance sustainability [6].

Manufacturability: This presents about the various approaches by which manufacturing of products can be achieved. Parts of these approaches are lean manufacturing, just in-time manufacturing approach, conventional approach, automated processes, just to mention a few. Once there is need to formulate maintenance strategy or approach, this factor cannot but be considered. The effect of this factor will be demonstrated in Section 1.4.

Functionality: Functionality is based on the condition at which the product to be produced is required. Some products require high precision, accuracy and uncompromised quality. If machines meant to produce such products are not fully sustained and maintained, then the aim for producing such products will be jeopardized as they will not be able to meet their functionalities in the intended field of operations. In other words, for maintenance strategy to be proposed for such set of machines, the maintenance manager must put this factor into consideration.

The technical know-how of any maintenance manager on the above factors will assist in his choice of maintenance strategy formulation in proffering the most sustaining practice. Various maintenance strategies are being discussed in Section 1.2.

1.2. Maintenance strategies

Maintenance strategies can be categorized into four major types:

i. Reactive/corrective/breakdown maintenance

ii. Preventive maintenance

iii. Improvement or design-out maintenance and

iv. Terotechnology maintenance strategy

Preventive maintenance can be subdivided into two major types, namely:

i. Periodic maintenance

ii. Predictive maintenance

These periodic and predictive maintenance are well subdivided into two types each as shown in **Figure 1**. The periodic maintenance is divided into routine and scheduled maintenance, whereas the predictive maintenance is divided into condition monitor maintenance and condition-based preventive maintenance [5].

Figure 2 shows the three broad categories plus terotechnology, which is the latest development in maintenance engineering. Preventive maintenance is being split into two subcategories. All the seven categories have been arranged in progressive order of effectiveness in terms of scientific value, colour coding and cost of such a maintenance programme. Although design-out maintenance and terotechnology maintenance strategies have (same) green colour, it is an indication that the practice is efficient, safe and mostly equal in its service delivery to the upkeep of plant. These strategies shall be briefly discussed in the order at which they are spelt out in **Figure 2**.

1.2.1. Reactive maintenance

This is also termed to be **run to failure maintenance or c**orrective maintenance or **b**reakdown maintenance. These are operations carried out to restore a machine to operative condition after a breakdown, accident, wear, etc. Since these activities are generally not known in advance and therefore cannot be scheduled, they are often referred to as unscheduled, emergency or

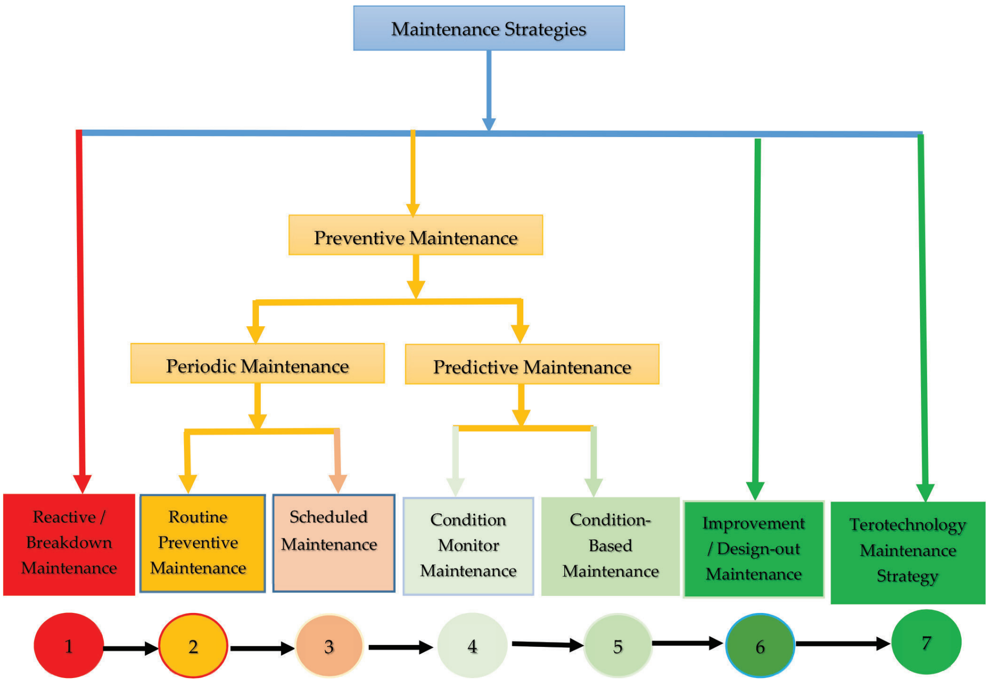

Figure 2. Modified maintenance strategies indicating ascending order of technology effectiveness [5].

repair maintenance. In this type of maintenance, there is no routine maintenance task performed on the equipment until after it has suffered a failure. In other words, machines are repaired or replaced upon failure. It is the simplest approach to maintenance and equally the least effective. It can only be practiced in an industry or applied to equipments that are inexpensive, largely duplicated and easy to repair or replace.

1.2.2. Preventive maintenance

Preventive maintenance is hinged on activities put in-place prior to machinery breakdown or failure of its component parts. It is aimed at ensuring smooth production/machine running that will lead to high product quality and minimal or zero (0) % materials wastage. Production systems repaired or maintenance are scheduled or planned regularly at set interval of time. It uses the tools of condition monitoring where critical component parts are being monitored [7].

Preventive maintenance can be subdivided into periodic and predictive maintenance. These subgroups can be further subdivided into routine and scheduled maintenance and condition monitor (or condition monitoring) and on-condition maintenance, respectively.

Routine preventive maintenance: These are maintenance operations, not involving disassembly or replacement of components and comprising mainly of cleaning and adjustments, which are carried out regularly such as every hour, every day, or every week.

Scheduled maintenance: This is maintenance in which preventive activities are scheduled for fixed intervals that are much longer than routine intervals. Moreover, these activities include oiling, greasing, adjustments, replacement of parts, etc. This type of maintenance may be due to government regulations, scheduling of downtime around production operations, availability of special personnel or simply the need for a finite standard that can be understood by everyone involved (e.g. oil changes).

1.2.3. Predictive maintenance

Predictive maintenance is a maintenance practice aimed at predicting the performance behaviour of machinery and their component parts in order to take necessary steps in averting the occurrence of intending and incipient failures and breakdown and its consequences. It uses prognosis tools principle as basis for its operation which is based on monitoring the equipment's condition.

Predictive maintenance allows failures to be forecasted through analysis of the equipment's condition. Thus, it ensures high service. Its analysis is generally conducted through some forms of trending on parameters like vibration, temperature, noise/acoustic sound and lubricant/oil flow in the machinery.

1.2.4. Condition monitor maintenance

Condition monitor maintenance is a self-scheduled, machine-cued predictive maintenance that is based on the periodic, and sometimes continuous, measurement of one or several parameters of condition in an equipment such that a significant change is indicative of a developing failure. Examples are measurement of the viscosity of engine oil in a working machine or the amplitude of vibration of rotating machinery. The evolution of these parameters is considered to be representative of the actual condition of the machine. However, a deviation from a reference value (e.g. temperature, viscosity or vibration amplitude) must occur to identify impending damages. In failure detection, the emphasis is on inspection and test because that is the best way to determine whether warning signs of impending failure are occurring. In order for condition monitoring to be effective, the failure must not be catastrophic. The pay-off from inspection is best with a slow wear-out situation

1.2.5. Condition-based maintenance

Maintenance carried out in response to a significant deterioration in a plant unit as indicated by a change in a monitored parameter of the unit condition or performance is called condition-based maintenance. It uses the machine condition monitoring tools discussed in Section 1.1. vis-à-vis: vibration monitoring tools, thermal monitoring tools, sound monitoring tools, acoustic emission monitoring tool, shock pulse monitoring tools, strain load monitoring tool, lubricant monitoring tools, corrosion monitoring tools, crack detection tools, ultrasonic tools and flux monitoring tools. All these aimed at giving: good indication whenever machine is running smoothly and efficiently or otherwise for failed condition; giving early sign of warning when fault is noticed and providing diagnoses for developed faults.

1.2.6. Design-out (improvement) maintenance

Considering scientific values and overall cost implication, design-out maintenance is the most effective maintenance strategy to be embarked on. It aims at eliminating the effect of failure. The design-out maintenance approach initiates learning system, which collects and provides information on maintenance problems as a feedback loop to design.

Design-out maintenance is usually a phenomenon for areas of high maintenance cost resulting from poor design or operating outside initial design specifications. In a nut-shell, design-out maintenance is to pre-act to eliminate failure instead of reacting to failure [5].

1.2.7. Terotechnology

Terotechnology is the technology of installation, commissioning, operation, maintenance and feedback to design of plan, machinery and installation. **Figure 3** shows various stages of an equipment life cycle and the role of terotechnology.

At design stage, terotechnology concentrates on reliability and maintainability factors, which should be considered in relation to equipment performance, capital, running costs and environmental influence. At manufacture, it concentrates on quality control and design fault detection. While at installation, it focuses on maintainability as the multi-dimensional nature of most of the anticipated maintenance problems (mainly on logistics) begin to clarify. During operation of machines, the technology establishes a learning system, which is to collect and

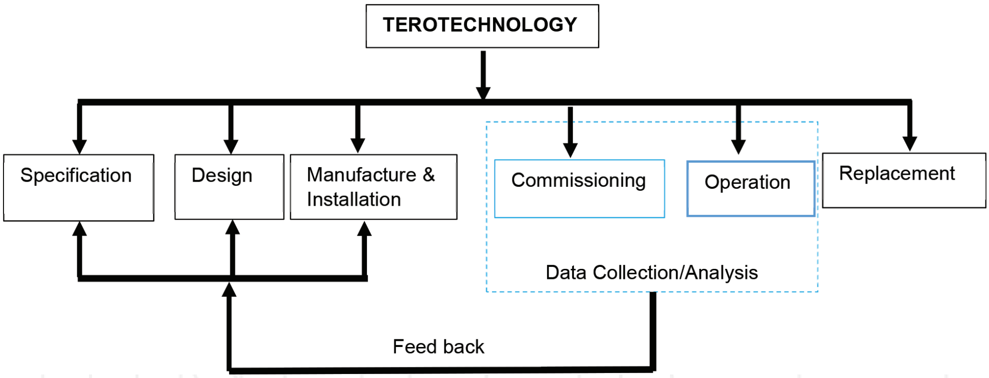

Figure 3. Adapted role of terotechnology in equipment life cycle [5].

provide information on maintenance problems with a view to improving the design to eliminate or reduce maintenance cost.

1.3. Selection guidelines for sustainable monitoring programme for machinery

In order to aid the readers/maintenance engineers understanding on how to know the suitable maintenance practice to adopt for any given machinery, a broad category of machinery classification is made as critical, major support and minor support. Possible failure results associated with these machineries are proposed with possible parameters to use in monitoring their behaviour. Also, the level of monitoring programmes that are needed to be put in place for their sustainability is proffered as contained in **Figure 4**.

For example, critical machinery with 100% production loss can be maintained by observing and monitoring the following parameters: vibration, oil lubricant, thermal behaviour or any specialized method using permanent on-line monitoring technique, spectral analysis, trend monitoring and computerized analysis, whereas minor support machinery with no production loss would not call for any condition monitoring attention. If it is called, it is an indication that the manufacturing enterprise is at the verge of incurring resources waste, which will no more be classified as sustainable manufacturing and maintenance practice.

Another comprehensive approach to matching of maintenance strategies based on manufacturing functionality is given in **Table 4**. Here, some manufacturing methods are highlighted with their appropriate suggested maintenance strategies.

1.4. Maintenance model formulation for different manufacturing methods at varying competitive environment

This subsection discusses modelling as part of tools that serve as indicator that could help indicating what is required to be done. Briefly, two scenarios in the use of models shall be looked into by considering some parameters on environmental impact such as demand, competition, cost and age-based policy on single component.

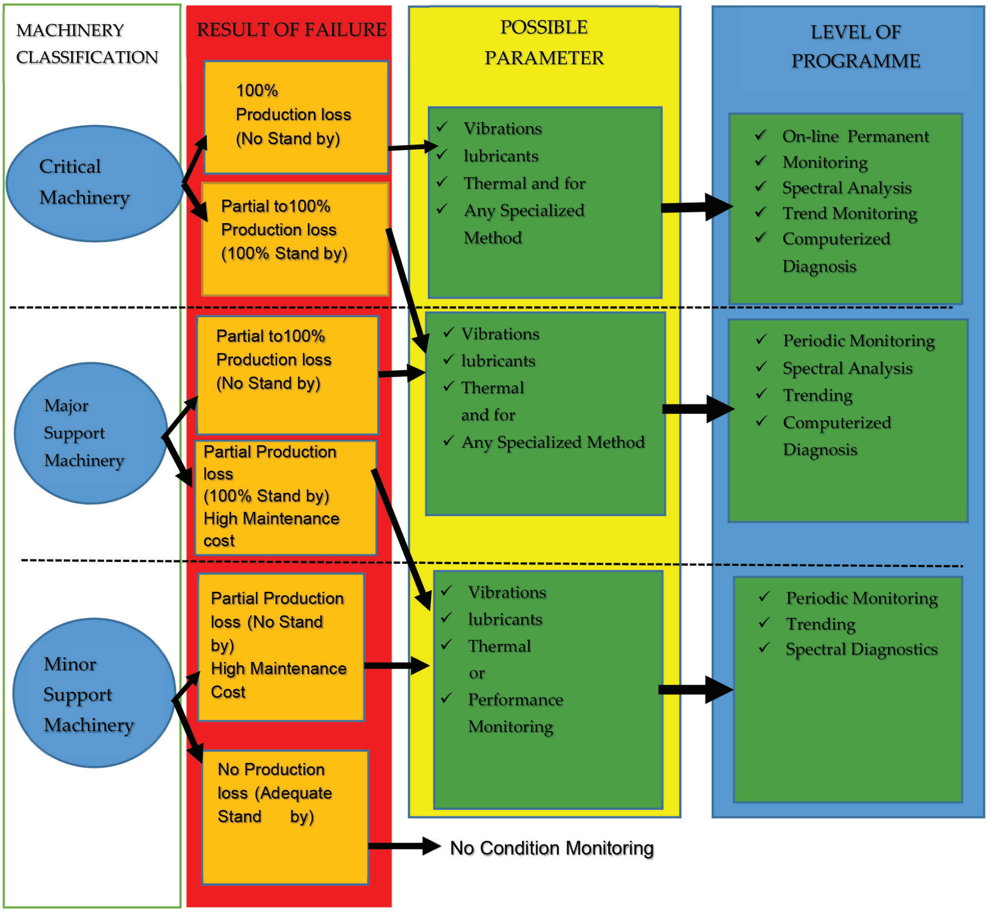

Figure 4. Re-modified application guide model for machinery condition monitoring [5].

1.4.1. Maintenance model for varying products demand and competitive environment

Adeyeri et al. [14] and Adeyeri and Kareem [6] formulated models that could assist in industrial decision making by considering the competitiveness of products and the number of manufacturers involved in producing such product(s). The model formulated is vast in predicting and matching the type of manufacturing to use at varying demand levels of product and as well as establishing the maintenance practice to adopt in order to minimize resource wastage and inventory cost. Based on this, **Table 5** gives the guide to how the prominent manufacturing practices, namely automated processes (AUTO), conventional process (CON) and just in-time manufacturing (JIT), can be married to the right maintenance activities under a varying market condition range of severity. The range of severity is a factor that determines whether to carry-out preventive, breakdown and predictive maintenance, or their combination in group or not.

S/N	Manufacturing functionality/ description	Maintenance practice description	References for explicit study
1.	• Mainly industry 4.0 manufacturing settings • Autonomic manufacturing systems • Integrated manufacturing system	• S-maintenance management system • Intelligent maintenance system • Use of domain expert knowledge	[8]
2.	• Flexible manufacturing system • Flexible manufacturing cell • E-manufacturing	• E-maintenance management system • Use of Information Communication Technology (ICT) and real-time monitoring sensors strategy	[9]
3.	• Competitive manufacturing environment	• Dynamic maintenance • customer-demand induced maintenance planning technique	[6]
4	• Quality oriented manufacturing system	• Total quality maintenance • Use of intensive real-time data acquisition and analysis to detect causes behind deviation in product quality • Use of overall process effectiveness (OPE) strategy	[10]
5	• Distributed stream manufacturing (processing) system	• Predictive failure management system • Online failure prediction to achieve selective, just in-time and informed failure prevention • It uses light weight stream classifiers to achieve online failure prediction which continuously classifies received feature samples into three states: normal, alert and failure • The classifier raises failure alerts when the component state falls into the alert or failure state. The classifier is continuously updated using labelled measurement data	[11]
6	• General purpose machinery	• Maintenance management application based on artificial intelligence and knowledge-based principles	[12]
7	• Multi-component system in continuous manufacturing units (Petrol Chemical Plant)	• Opportunistic maintenance policy • Combined algorithm for preventive corrective and opportunistic maintenance plan	[13]

Table 4. Suggested sustainable maintenance approaches based on manufacturing functionality.

1.4.2. Maintenance model formulation for age-based single component

Laggoune et al. [13] is known that if the corrective and preventive maintenance costs for a component i and its failure distribution established, the expected cost per unit time is expressed as the sum of the expected corrective and preventive costs divided by the expected cycle length.

Parameter definition on manufacturing production target setup, product demand and range of severity	The suggested/preferred suitable maintenance practice to adopt	Preferred production method
Production output is less than demand with range of severity less than 0.5	Breakdown maintenance coupled with opportunistic maintenance practices	Automation manufacturing is more appropriate
Production output is less than demand with range of severity greater than 0.5	Preventive and dynamic maintenance are preferred	Automation manufacturing is preferred
Production output is greater than demand with range of severity less than 0.5	Breakdown maintenance integrated with static grouping is preferred	Conventional approach to manufacturing
Production output is greater than demand with range of severity greater than 0.5	Preventive and predictive maintenance are recommended	Conventional approach to manufacturing
Production output equals to demand with range of severity less than 0.5	Dynamic maintenance with opportunistic approach will do better	Just in-time approach is recommended
Production output equals to demand with range of severity greater than 0.5	Opportunistic or static maintenance strategy is preferred	Just in-time approach is recommended

Table 5. Suggested sustainable maintenance approaches based on production target setup and production approach.

$$C_i(\tau_i) = \frac{C_i^c F_i(\tau_i) + C_i^p\left(1 - F_i(\tau_i)\right)}{\int_0^{\tau_i}\left(1 - F_i(t)dt\right.} \tag{2}$$

Where $C_i(\tau_i)$ is the cost rate component i (objective function of the mono-component policy), C_i^c is the specific corrective cost, to be paid at each replacement upon failure of component i, τ_i is the time (age) for the preventive replacement of component i and $F_i(\tau_i)$ is failure probability distribution, it represents the cumulative distribution function (CDF) of the random variable 'time to failure' and can be obtained from historical failure data.

1.4.3. Equivalent mono-component approach

The mono-component approach entails modelling failed components together according to their failure pattern and time. It gives precedence to their failure time knowing fully well that once a component fails it leads to the complete shutdown of the system. Equation (3) expresses the system replacement cycle to be [13]:

$$\int_0^{\tau} \prod_{i=0}^{q} (1 - F_i(t))dt \tag{3}$$

which makes the system total cost per time unit to be expressed as:

$$C_{\mathrm{mono}}(\tau) = \frac{\left(C_0^c + \sum_{i=1}^{q} C_i^c\right) F_{sys}(\tau) + \left(C_0^p + \sum_{i=1}^{q} C_i^p\left[1 - F_{sys}(\tau)\right]\right)}{\int_0^{\tau} \prod_{i=1}^{q} \left[1 - F_i\right]} \tag{4}$$

Where $F_{sys}(\tau) = 1 - r_{sys}(\tau) = 1 - \prod_{i=1}^{q}\left[1 - F_i(\tau)\right]$ is the failure probability of the overall system and $R_{sys}(\tau)$ is the system reliability.

This maintenance plan seems to be sustainable if and only if the systems of same components with similar lifetime distribution [13].

1.4.4. Flowchart model on choice of maintenance for manufacturing system based on sustainable development perspective

Manufacturing system on the basis of developmental growth was classified as mass manufacturing system, lean manufacturing, green manufacturing and sustainable manufacturing system [15]. They are characterized and identified by cost reduction policy; waste reduction strategies; environmental friendly encapsulated by reuse, reduce and recycle principles and innovative product phenomenon wrapped in remanufacturing, redesign, recover, recycle, reuse and reduce concepts [16]. A flowchart for choosing the best production system as well as the maintenance strategy sustainable by the chosen manufacturing system based on the consideration of set goals and parameters at which the manufacturer decides on is presented in **Figure 5**. On the basis of the flowchart explanation, assuming a manufacture has it in mind of having a manufacturing system that is environmentally inclined and can as well support the reuse, reduce and recycle (3R) principles, as the flowchart is initiated, the flowchart will suggest that the best manufacturing system suitable for the set goals is ‘green manufacturing matched with green maintenance practices’. After this, it will still be interested in knowing the outcome of the choice if indeed it is sustainably satisfactory after it has been implemented.

1.5. Steps for improving sustainable maintenance plan

Having done all necessary activities in putting up a sustainable maintenance practice for any category of machineries, it is as well expedient to see the improvement of these maintenance plans. In view of this, **Figure 6** shows the nine steps for improving any maintenance plan. The first three steps are referred to as the data acquisition cycle where process history and overall equipment effectiveness are being measured. The next four steps describe the equipment status cycle where critical assessment, appraisal of set out condition and refurbishment are being carried out. The last two steps centered on proactive measure cycle.

1.6. The required skills for maintenance sustainability paradigm frontiers

Skill is the safe technical know-how or hands-on ability to appropriate available technology in solving challenges within the limited available resources at zero level of materials and resources waste. The man behind the scene who will be able to appropriate all the aforementioned practices in this chapter must possess all the following skills and virtues. If any of these skills is missing, the sustainability goals will not be achieved.

i. **Knowledge competence of the field**: The basic requirement for potential maintenance engineers lies on the acquired knowledge skills competence which is got through formal education and training on specialized fields of study. It involves training on machine learning; machines and systems dynamics; hydraulic system and its principles of operations; machine modelling and its kinetics, just to mention a few. Acquiring this knowledge will accelerate the performance rating of the maintenance engineers to be.

ii. **Scientific knowledge**: In addition to knowledge competence, the scientific knowledge encompasses the general knowledge of applied principles and methods in the mechanical, electrical electronics, mechatronics and systems engineering. A maintenance engineer should be able to distinguish between single phase or three-phase power and what type of load they are meant to be used for. In distinguishing between them lies on the scientific knowledge understand of the engineer.

iii. **Design creative skills**: In engineering world, the medium of expression is through drawing design. Therefore, for every idea or concept conceived by the maintenance engineer, he or she should be able to communicate this in drawing. To go further, such an idea when communicated in drawings can be simulated to see the reality of how the concept improves the production facilities setup.

iv. **Interpretation of engineering drawing and symbols**: The ability to read and interpret design drawings and symbols from manuals provided on equipment or machines is required from the 'to be maintenance engineer'. If these drawings are wrongly interpreted, it will result to resource wastage as damages may occur in the course of the process. When damages are incurred, the principle of sustainability has been violated. Therefore, dreading and interpretation of drawings importance cannot be overlooked.

v. **Proactive instinct of thinking and analytical minds in decision making**: A good maintenance engineer must be proactive in decision making. Whenever it comes to decision on machines maintenance actions, he should be able to project above reactive thinking to solution provision on critical components, rather, he should give suggestion that will prevent the occurrence of the failure which is being addressed.

vi. **Good listening ability and skills to distinguish between sounds and acoustic output by matching them with probable cause roots of faults and failure**: When machinery is in use, inherent noise and sound are associated with machines as a result of vibration effect and motion-related issues. The recognition of sound produced above the required threshold frequency because of compromise in the machine's integrity as a result of change in its attenuation will help in knowing the decision to take. Therefore, exhibiting this ability will help in detecting the onset of failure and thus prevent further degradation of the components and machine as a whole.

vii. **Ability to match the best maintenance strategy with any production setup and its machines**: Knowing the various maintenance strategies is not enough, but the ability to marry or match the required strategy with the manufacturing setup will be more beneficial. This chapter has moved further by giving blue print scenario of cases and guidance on how maintenance could be matched with appropriate manufacturing setup.

viii. **Trouble shooting and diagnostic skills**: He or she must be able to run a series of analytical questions and tests that will lead to the detection, isolation and identification of probable faulty component parts.

ix. **Good in record keeping**: Information on machinery behaviour can only be made known through the processed data retrieved from the machines. It is imperative that any prospective maintenance engineer must have good record keeping habit.

x. **Good team spirit**: There are some repairs or faults that will require the expertize of others in the area where the incumbent maintenance engineer's knowledge is limited; in such a situation, there is need to collaborate for assistance so as to minimize time wastage in repairing the fault.

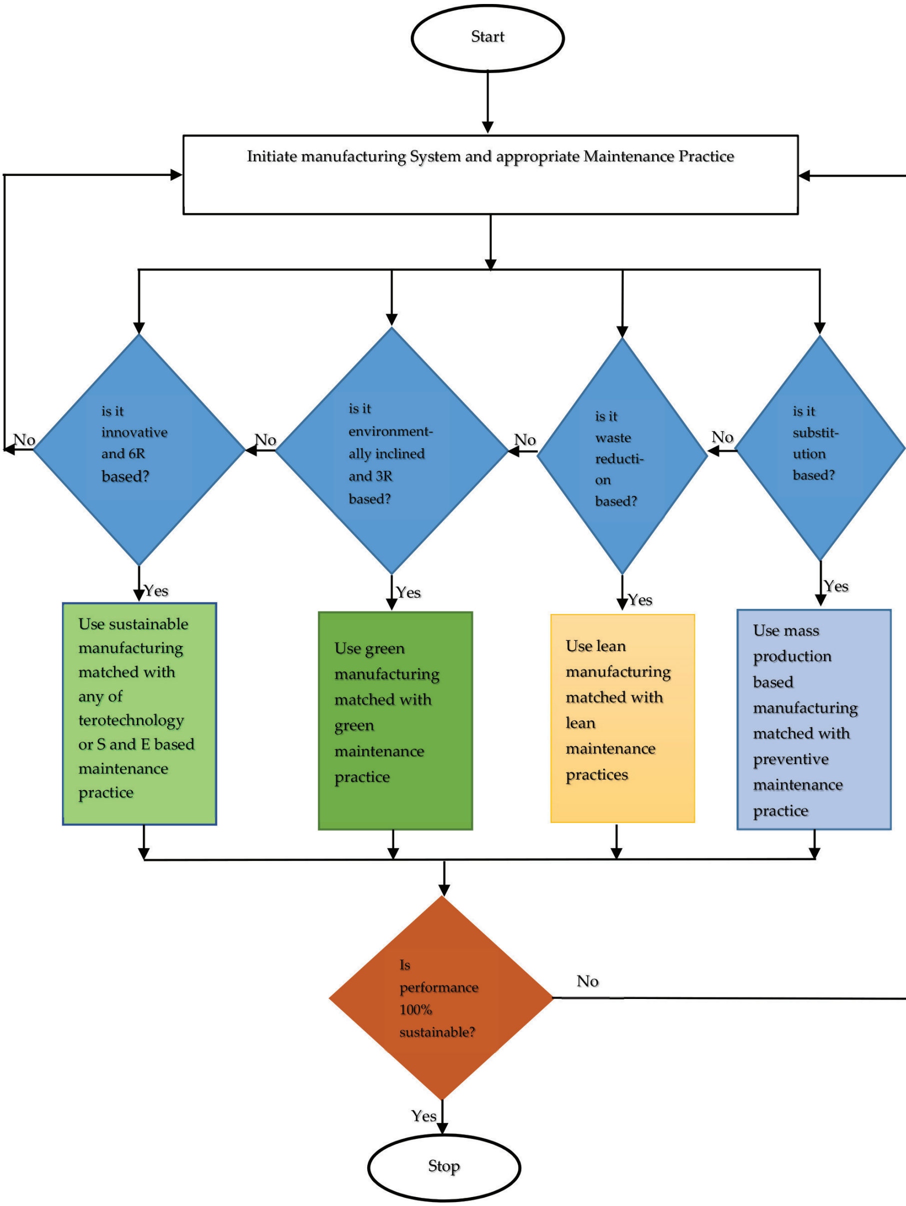

Figure 5. Flowchart for matching manufacturing system with maintenance strategy.

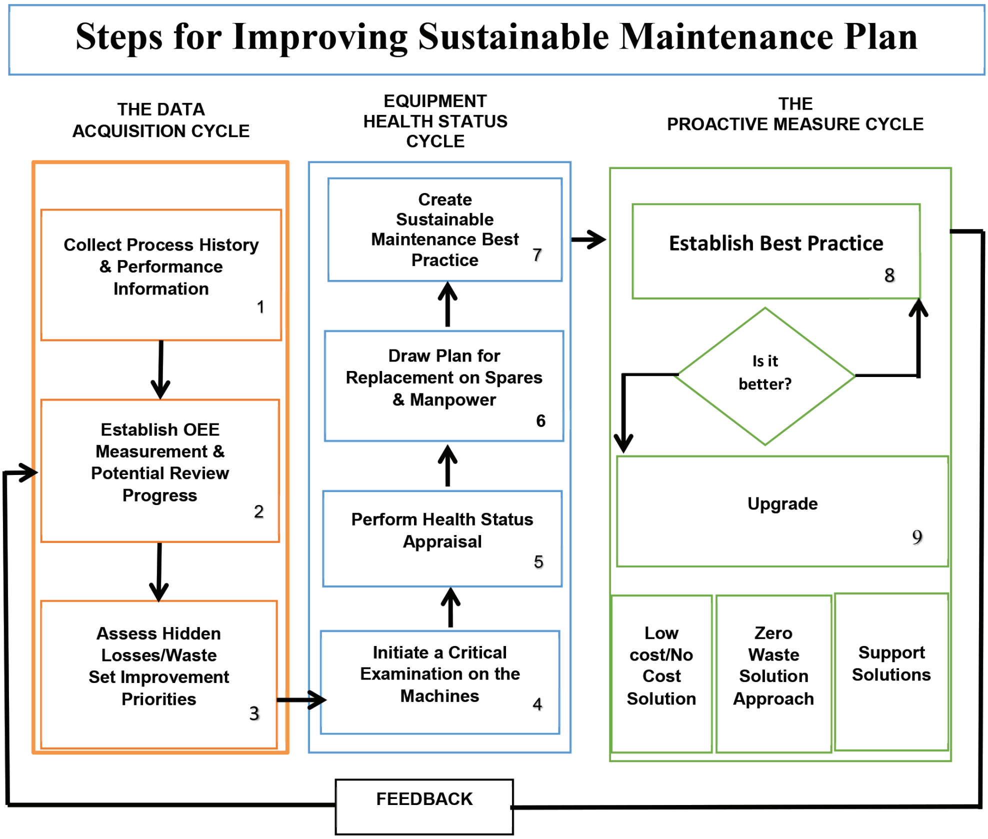

Figure 6. Steps for improving sustainable maintenance plan [17].

1.7. Conclusion

The chapter has established the major ingredients of sustainable maintenance practice, which is indeed novel, and as well established different groupings at which various manufacturing strategies could be matched with the best maintenance practice depending on the factor being considered. Also, the proposed sustainable maintenance prediction algorithm plan has richly provided the platform on which the best maintenance strategy could be practiced at minimal cost and reduced waste level under a competitive business world. The chapter has also assisted in viewing sustainable manufacturing practices from the angle of manufacturing functionality machinery classification and the industrial growth perspective. All these three categories of production or manufacturing strategies were all matched with the best sustainable maintenance practices. The system component policy models have laid foundation for robust replacement plan and holistic maintenance practice. Therefore, the maintenance plan if followed dogmatically with high sense of expertize has the potential for substantially reducing the operating costs and for increasing corporate profit by increasing availability and production.

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In addition, successful implementation of this instructive methodology will reduce wastages, eliminate machine downtime, increase machines performance with improved functionality of parts thereby providing maximum usability and reusability of parts/components and thus increase the machine optimal functionality and efficiency.

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Chapter 4

Interventions to Skills Development in the Automotive Manufacturing Sector of South Africa

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Grace Mukondeleli Kanakana

Additional information is available at the end of the chapter

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Abstract

Competitiveness of the automotive industry is critical to South Africa's economic sustainability. Recent studies have shown that the automotive sector has consistently contributed over 7% to South Africa's annual gross domestic product (GDP) and as such, it is particularly imperative to support this sector, through growth-stimulating measures. Economic growth of any nation has long been attributed to the availability of resources, both tangible and intangible. Human capital is thus far the greatest intangible asset recorded in history and it is the key element upon which the success of all sectors is predicated. The availability of foreign direct investment (FDI) has largely been credited to the level of skilled and proficient human resources within an economy. This chapter highlights the strategic position of the South Africa automotive industry, by discussing various skills development interventions recorded within this sector from a domestic standpoint and from an international perspective. It comparatively analyses the approach applied locally with those implemented in other countries, through a historical review of skills development measures within the automotive manufacturing sector. The chapter identifies the major stakeholders, their roles and recognized contributions toward establishing a sustainable automotive sector. The skills development frameworks discussed in this chapter will serve as bases for informed decision to other industries interested in adapting and replicating some of the plausible actions applied in the automotive sector for their own growth.

Keywords: skills, South Africa, automotive, interventions, skill development, automobile, manufacturing

1. Introduction

The automotive sector has witnessed significant improvement in terms of innovation within the past decade. Notably, material, skills and process improvement have taken the center stage, with availability of skilled labor emerging a major component for global competitiveness ranking in this dynamic industry. A roadmap to achieve the Automotive Production Development Programme (APDP) growth targets in South Africa's automotive industrial space is currently in place and skill development is a key to achieving these goals. There have been significant investments over the past decade channeled toward filling skill gaps in this sector. Incubation and learning centers, supplier parks and specialized skills development institutions have been setup in a bid to stimulate skill development that will effectively satisfy current and future growth projections, toward achieving the year 2020 automotive industry production target of one million vehicles annually. As such, structures were set up to promote institution-industry collaborations, and synergies were encouraged, established and maintained for the purpose of sustainability. Recognized Technical and Vocational Educational Training Colleges (TVET colleges) and Further Education and Training Colleges (FET colleges) have been engaged, and specialized centers have been set up in higher educational institutions through the Sector Education and Training Authorities (SETA) skills development framework. Through these measures, the wide gap that once existed between South Africa automotive manufacturing industries and post-secondary educational institutions have significantly thinned out. Notwithstanding, opportunities abound for more co-funded projects which should be directed toward localizing skills development in the Research and Development (R&D) space.

The South African automotive industry is conceivably struggling to keep pace with global competition as inferred from key performance indicators derived from statistical report on the overall production volumes and export volumes of vehicles, comparative to international counterparts. The employee skill base of this sector is one of the indicators for testing its health, and its potential of satisfying production and international regulatory demands. Furthermore, the actualization of the automotive sector's targets within the 2030 national development plan of South Africa is largely hinged on the availability of skilled workforce that are continuously keeping pace with changing global skill demand. The review in this chapter reveals skills transfer interventions in the South Africa automotive industry, based on the collective effort of the government and key stakeholders. The approach to the study is from an industrial and educational standpoint, because of the author's affiliation to a higher institution and to the Manufacturing engineering and related services SETA (MerSETA).

Some of the interventions and current framework for skills development within the South Africa automotive sector were informed by research findings on critical skills need and skilled employee gaps identified within the sector. More of the studies have explored how industry needs are being met by exploring the knowledge areas of the interventions, their mode of delivery and the focus group of people within the enterprises who undergo such capacity development programs. The objective of this chapter is to discuss various skills development interventions recorded within the automotive manufacturing sector from a domestic standpoint and from an international perspective. Historical review of skills development measures within the automotive manufacturing sector identifies some of the lapses and strength of various programs and initiatives toward realizing an industry-wide competence development. The chapter identifies the major stakeholders, their roles and recognized contributions toward establishing a sustainable automotive sector. Lessons learnt from the skills development frameworks discussed in this chapter will guide other industries who may be interested in establishing similar workforce skills transfer initiatives. Part of what is being shared are relevant case study findings that emerged from practical productivity improvement programs carried out in the South African automotive manufacturing sector. The details herein were acquired through group discussions, practical intervention results and literature review from published works. Training officers and knowledge base managers within the automotive industry learning centers were interviewed and qualitative and quantitative data were obtained. Industry stakeholders verified the information obtained during the study, and extensive cross-referencing formed part of the validation.

1.1. The automotive sector

The automotive assembly and component manufacturing industry represents an important sector in South Africa's economy. According to the Automotive Supply Chain Competitiveness Initiative [1], the sector accounted for a third of total manufacturing output in 2015 and employed over 110,000 individuals. The local production was 615,658 vehicles in 2015, mandated to rise to a million units by 2020. This topic will be incomplete without a summarized discussion on the distinction between various categories of enterprises operating within the automotive manufacturing sector. Automotive manufacturers are generally categorized according to their size (number of employees), their position in the supply chain and the product variant. Depending on the classification, the regulatory standard differs. These include variation in Technical Specification (TS) and International Organization for Standardization (ISO) protocols enforced by the regulatory agencies. Original Equipment Manufacturers (OEMs) are at the top of the automotive value chain, and these are the vehicle brands: BMW, Mercedes Benz, Toyota, Nissan, Ford, Hyundai, Volkswagen and other makes. The second layer on the pyramid is the module suppliers which build the final component that goes into the vehicles. They are usually referred to as Tier1 automotive manufacturers and are direct suppliers of modular components to the OEMs. Enterprises within this category supply component such as complete exhaust assembly, windscreen/windshield assembly, electronic control systems, chassis, coupled seats, coupled mirror assemblies, lighting assembly, complete dash, complete gear system and interior and exterior parts. These are very large enterprises and are often quite similar to the OEMs in their production operations. Enterprises within this category source their components from approved Tier2 automotive component producers. Tier2 producers are significant within the automotive value chain because they produce the mini components that Tier1 enterprises utilize. Enterprises within this category produce brake pads, brake disks, vehicle seat frames/foam, fasteners, mirror, cooling fans and similar micro components. Because of the thin difference between the Tier1 and Tier2 firms, some companies operate both as Tier1 and Tier2 suppliers having met the requirements to operate in both industry spheres. As an example, consider Kayaba

(KYB) industry corporation, one of the world's largest vehicle shock absorber producer; the company fall within the Tier1 category, based on their supply to OEMs, and may inappropriately be considered as a Tier2 enterprise due to their supply of vehicle replacement parts to automotive aftermarket value chain. The distinguishing factor will simply be the number of employees because it is a major determinant for categorizing the manufactures within the automotive sector. Tier3 suppliers are those Small and Medium scale Enterprises (SMEs) that provide the raw materials to Tier2 components producers. Companies within this category supply chemical reagents, adhesives, fasteners, raw materials and final body finish.

The automotive industry is extremely robust and skilled employees are essential through the value chain. Ideally, prioritization of Research and Development (R&D) is imperative at all levels. However, findings from industry engagement in a large number of automotive suppliers within South Africa is that Tier3 suppliers depend absolutely on the demand made by Tier2 suppliers and little or no R&D take place at this level. The Tier1 suppliers and OEMs execute the bulk of R&D and advanced R&D is simply outside trusted R&D providers outside the continent. Based on this reality, a holistic approach to skills development is essential in order to meet the changing demand at all levels. OEMs and Tier1s have had to depend on foreign import in South Africa amidst the tight import regulations due to skill gaps that sometimes encountered. Past programs and current skill development initiatives within the automotive sector form the crust of the discussion, aimed at identifying best practices that have been applied and found effective.

2. A critical review of skilled employee training needs, training approach and employee retention in the automotive industry

Historically, skills transfer occurs as critical need for it arises within an industry. The industrial revolution that transformed the course of man's history reckoned with this philosophy because new disciplines evolved and skills emerged during that period. Over the years, this has changes because industries now have to be ahead of the competition in a dynamic and fast changing industrial environment where technology and innovation dictates the pace at which human capacity get upgraded. According to a study undertaken by Skinner et al. [2], differences in perception of what is needed and how feasible it is to apply same determines what skills are acquired. From the educators' perspective, the study revealed that institutions and vocational education and training colleges simply respond to the demand received from the automotive industry for certain skill set.

Petersen et al. [3] carried out a research on methods of bridging skills demand and supply in South Africa. From the study, Petersen et al. [3] concluded that demand-led skills development requires linkages and coordination between firms, education and training institutions, which may be quite challenging simply because each of these entities represents a self-interested unit. He further expressed the need for collaborative projects involving major stakeholders across the board. The need for a pragmatic transition toward systemic thinking, which facilitates the bridge of public and private objectives, came out strong from the study.

Furthermore, also acknowledged were the roles of private intermediaries' in shaping policies. Other authors have also shared the similar views regarding demand-led skills development. According to Petersen et al. [3], the South African government is promoting a demand-led approach to skills development, to improve alignment between the qualifications and skills produced by education and training systems and labor market demand.

Public-private intermediaries play crucial role of coordination, which has the potential of contributing largely to systemic functioning [3]. Kraak [4] elaborated on the role of intermediaries in skills development. The focus has been on the role of public intermediaries such as the Sector Education and Training Authorities (SETAs) in facilitating bilateral relations, and linking the state and employers. The categorization of intermediaries is according to the intermediaries' structures and the mode of facilitating linkages. Of significant importance are the public research institutions, intergovernmental and technical aid support agencies, government agencies and private intermediaries. Intarakumnerd and Chaoroenporn [5, 6] equally stressed the need to better understand the roles of public and private intermediaries in skills development, to improve alignment between skills demand-side and supply-side actors. The building of linkages is a major step in the right direction for addressing skill needs. These linkages may be between firms; government and firms; educational institutions and firms; international accredited support agencies and unions, among other possibilities.

Employee retention is critical to the successful operation of any business unit. In human resource context, the turnover of employees must be at the barest minimum to remain competitive. Manufacturing firms cannot achieve desired goals without a system that retains consistent skilled employees. Many companies within the South Africa automotive industry have witnessed severe operational glitches that emanates from sudden departure of trained employees. Low retention of scarce skills has been an issue affecting optimal operation of industries. More challenging is the recruitment of scares skilled personnel which has become an expensive undertaking for industries and has prompted unsatisfactory shift in standards, which invariably have negative competitiveness implications for the South African automotive components industry.

Dufficy [7] recognized the role of training for employee retention. Based on his research on recruitment and retention, he identified the role of training to business success in the current world. "At a time of growing skills shortages across a wide range of sectors, disciplines and geographies plays a central role in finding and keeping staff. With many companies moving toward flatter, team-based structures, there is an implicit need for greater multi-skilling, the whole concept of the learning organization and learning for life is focused on acquisition of additional skills and competencies" [7]. These skills development opportunities aid retention because of the job satisfaction derived by employees because of competence improvement deliberately facilitated by the organization. Skills development in specific area of competence also raises the marketability and financial reward that comes with positions with expected set skills. Employees show more level of comfort, confidence and focus when there is continuous improvement in their competence level, which shows in their ability to satisfy the expected work outcome.

Barnes [8] undertook a research on scarce and critical skills need in the South Africa's automotive sector based on an earlier study carried out by the Department of Labor. Recruitment lead times,

Category	MerSETA study	DOL study	HSRC report
Engineering professional	Electrical, mechanical, industrial and metallurgical engineering	Product designers, industrial, mechanical, mechatronics, industrial/product development technologists	Electrical, mechanical and industrial engineers
Trade skills	• Mechanical, fabrication, electrical and automation. In terms of operators: • Manufacturing and engineering production operators and stationary plant operators.	Engineering technicians: electrical, mechanical, mechatronics, robotics and tool design • Electricians • Electronics trades workers: (electronics/electronic equipment's) • Fabrication engineering trade workers: sheet metals, structural steel welding, metal fabricators. • Vehicle body builders and trimmers. • Vehicle painters • Mechanical engineering trade workers: metal fitters/machine tool setters, millwright, mechatronics	Artisan skills: electricians, fitters and turners, millwrights, electronics, tool jig and die
Management	Engineering and operations middle management		Supervisor and production managers

Table 1. Comparative analysis of scarce and critical skills need in the automotive sector [8].

industry skill demand profile and skills shortages, formed the bases of the study. According to the firm-level findings from the research, all engineering qualifications, but most notably industrial and mechanical engineering, emerged as the key need areas within the industry [8].

Table 1 illustrates a comparative identification of the scarce skills needs according to the study carried. It describes the findings from the 2006 MerSETA skills need assessment, the Department of Labor (DOL) assessment and the study report documented in the Human Sciences Research Council (HSRC) Automotive Industry Research Report [8].

3. Automotive skills development: lessons from South Africa and from global industries

The approach to skills development has been an issue of discussion in various sectors. What works for employee within mid management level will not necessarily be applicable on the shop floor. Various skills transfer and capacity development methods have been proposed and there are no set rules which govern this training opportunities. Each organization and industry adopt what suites their needs; consequently, variety of short and long learning programs have been developed in this regard. Lean management is an approach adopted by top-class enterprises because of the value addition that comes through lean management principles. Toyota as an example has been able to integrate lean into every facet of its operations right from top management to shop floor. The training methodology, course contents, appraisal methods, learning outcomes and impact assessment methods of skills development interventions differ across programs. Organizations now focus more on broader areas of competence than isolated proficiency. According to Dufficy [7], training is increasingly focused on the acquisition of broad competencies which include change orientation, leadership and problem solving skills; rather than functional skills, which has reduced dependence on top-down prescriptive teaching in an era where employees recognize the significance of taking full responsibility for their skills upgrade.

Trainings have gone beyond conventional sessions in classrooms and client site, to virtual learning. Blended approach to training is currently a common norm, and with the increasing digitization of manufacturing environment, the role of online real time hands-on training will not be contestable. The learning curve is fast changing and this awareness is imperative in order to be up-to-date with the twenty-first century manufacturing skill demands. According to a research conducted by Dong-Min and Choi [9], Hyundai Motor Company has adopted highly innovative blended learning programs as far back as 2003, for developing its potential managers. This and similar case studies shall be discussed to fulfill the chapters' objective of sharing experiences from global perspectives.

3.1. South African perspective: national approach to automotive manufacturing skills development

There is a long skills development history in the South Africa automotive sector largely linked to government initiatives, local intermediaries and international actors. Kraak [4] in his study on the National Skills Development Strategy (NSDS) in South Africa highlighted the success and challenges facing skills development in South Africa. The highlight emanated from an evaluation of the impact of the first phase of the NSDS, between the first quarter of 2001 and the first quarter of 2005. The most significant limitations recorded in the skills development strategy were the lack of political will to ensure the success of the integrated approach to education and training after 1994, severe governance challenges involving management of Sector Education and Training Authorities (SETAs), financial misappropriation and myriad of operational problems. Because of the numerous setbacks, programs by other intermediaries emerged and previously existing once gained prominence [4].

Automotive Supply Chain Competitiveness Initiative (ASCCI): The Automotive Supply Chain Competitiveness Initiative (ASCCI) was established in 2013 with the mandate of coordinating supply chain developing activities within the South African automotive industry [1]. ASCCI is a collaborative initiative between suppliers, Original Equipment Manufacturers (OEMs), government and labor unions. It was established as a "not for profit" organization and the main mandate of ASCCI is to build a successful and sustainable local automotive industry by actively developing supply chain competitiveness at a national level.

Thus far, ASCCI has made progress in relation to the implementation of its three-year strategy that is intended to increase supplier Manufacturing Value Added (MVA) in support of growing local vehicle production output, increasing employment, enabling local supply chain capabilities, increasing local content and advancing transformation. ASCCI is a stakeholder driven initiative, drawing on the leadership and expertise of individuals from government, OEMs, suppliers and labor. The initiative has a small but well represented executive committee that takes responsibility for overseeing the implementation of associated projects and interventions. The objective of ASCCI's skills program is to establish skills development programs for shop floor and scarce skills that have sustainable funding and meet the support the industry's skills development needs [1].

ASCCI undertook a comprehensive research to unveil the industry's skills requirements, determine how they are being addressed, and define steps that will ensure training programs align with industry needs. ASCCI's current focus include establishing skills development committees that align best-in-class training institutions with the industry's skills development needs to optimize the availability and quality of skills. It also plans to establish a South Africa automotive industry skills development portal to align the industry with a set of quality skills development standards and resources. ASCCI is also considering creating a platform for aligning suppliers with global industry trends and competitiveness imperatives. Furthermore, through the development of a modularized management development program, it intends to provide enterprises with a mechanism to transform and upskill management to the level where they will independently operate an excellent manufacturing plant.

Motor Industry Development Programme (MIDP): The MIDP was a voluntary incentive scheme established in 1994, designed to save money for the participant, in the form of a reduction in import duties through incentives and rebates given to the MIDP. Government, business and labor unions jointly developed the program; and according to Barnes and Black [10], it was one of the most significant industrial policy interventions since 1994, both because of the powerful incentive structure it established and because of the sheer size of the industry it affected. The objective of the MIDP is to Improve International Competitiveness; thus aiming to produce more affordable motor vehicles for the local market, and increase production of these models for export. One of its core mandates is to encourage job creation and retention through learning and competence development opportunities. However, the benefits desired from this program in terms of skills development significantly eroded, because of the emergence of other agencies such as the Automotive Industry Development Centre (AIDC) and partly due to MIDP's focus, which tended more toward local production economics, manufacturing incentives and import matters. The skills development portfolio was still work in progress until it was dissolved. The Automotive Production and Development Programme (APDP) replaced the Motor Industry Development Programme (MIDP) in 2013. The APDP consists of four pillars, which include import duty, vehicle assembly allowance (VAA), production incentive (PI) and automotive investment scheme (AIS). Lessons learnt from the previous MIDP informed some of the pillars. The training/skills development component was expunged from the pillars because other organizations were meeting that need. One of the lessons learnt from MIDP regime is the need to prioritize skills development within a mandate because human capacity is the greatest intangible asset.

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According to ASCCI [1], increasing customer demands will put added pressure on the industry to deepen and widen its employee skills base. From an export perspective, South Africa Original Equipment Manufacturers (OEMs) and component manufacturers will meet the increased export quality demands, which is a clear indication of the much-needed skills across the automotive value chain. The skill need of the automotive industry is largely tied to the employment composition of the industry. To effectively analyze the skills demand in South Africa's automotive industry, HSRC from its automotive industry research report outlined the aggregated number of graduates in engineering, science, business management and technology from South Africa's tertiary education institutions [8]. Similarly, the National Association of Automotive Component and Allied Manufacturers (NAACAM) 2005 survey report on the labor composition of the automotive manufacturing sector explored the skill distribution of the components manufacturers based on employment composition [1]. The automotive components industry's composition report as prepared by B&M Analysts [8] summarizes the workforce distribution as at 2005. This is a good starting point for projecting skills development programs for an industry. However, little to none was explored regarding the skills deficit within each of the levels.

The Automotive Industry Development Centre (AIDC): AIDC is an established support center focused on addressing skills deficit challenges and skills transfer needs in the automotive industry. The Government established it in October 2000 at the request of the industry and it became operational by 2001. AIDC came to be through a partnership between Blue IQ and the Council for Scientific and Industrial Research of South Africa. It is currently an implementation agency of provincial government and has trained a large number of artisans, and supervisors within the automotive manufacturing sector. It has extensively collaborated with higher institutions in a bid to fulfill its mandate.

As part of Gauteng Provincial Government's commitment to skills development, AIDC and Nissan South Africa (NSA) launched the Gauteng Automotive Learning Centre in June 2014. The learning center is part of the Nissan SA investment support program. Under the terms of the collaboration, NSA provided the land and buildings at zero cost to AIDC and the collaboration agreement transferred the cost of utilities water and electricity to NSA. The funding for the construction of the new building and purchase of all equipment required for training purposes came from AIDC. The training program in the learning center is expected to address technical skill shortage experienced in the sector. The learning center has received full training provider (FTP) accreditation from MerSETA for the further education training certificate on National Qualification Framework (NQF) Level 4. Based on this accreditation, the learning center can train on the following general skills programs: passenger vehicle sales, commercial vehicle sales, vehicle servicing, motorcycle sales and part sales.

Furthermore, the learning center currently has accreditation to take technical courses in the following core programs: hydraulics (basic to advanced), pneumatics (basic to advanced), mechatronics systems and PLC & Codesys. Other technical programs to be offered are in CNC (5 axis machinery suitable for tooling), machining: fitting & turning, welding (simulated & practical) and basic hand skills. **Table 2** presents accredited courses and their qualifications level at the learning center.

Qualifications, learning and skills program	NQF level
National Certificate: Autotronics	Level 2–4
National Certificate: Mechatronics	Level 2–4
National Certificate: CNC Production Machining	Level 2–4
National Certificate: Diesel Electric and Electric Fitting	Level 2
National Certificate: Fitting and turning	Level 3
National Certificate: Diesel Electric and Electric Fitting	Level 3
National Certificate: Mechanical Engineering: Fitting	Level 3
Certificate: Fitting and Turning	Level 4
National Certificate: Automotive Spray Painting	Level 2
National Certificate: Automotive Body Repair	Level 2
National Certificate: Automotive Repair and Maintenance	Level 2
National Certificate: Automotive Components: Manufacturing and Assembly	Level 2–4
Further Education and Training Certificate: Automotive Sales and Support Services	Level 4
National Certificate: Welding Application and Practice	Level 2–4
Diesel Mechanic	Level 2–4
Auto Electrician	Level 2–4

Table 2. Courses and qualification levels at the learning center.

The learning center has an overall capacity that can accommodate approximately 1000 learners annually on a variety of training programs applicable to the needs of the automotive industry, for short- and long-term training programs. It is currently equipped with laboratories and technical workshops designed for hands-on learning and simulation of most operations obtainable in most shop floors. Currently, the learning center has collaborated with higher institutions with accredited mid-level managerial training courses. The learning center has thus far adopted the UNIDO Tirisano training module, which is a well-recognized training model utilized within industries in many nations. **Table 3** describes the modules and exit outcomes of the trainings.

Automotive Supplier Park (ASP): Automotive Supplier Park (ASP) is a Gauteng Provincial Government initiative and an international benchmark project that has contributed significantly to the global competitiveness of the South Africa automotive industry. It is aimed at stimulating economic growth and job creation in the automotive industry through large-scale investment in strategic economic infrastructure. The initiative enjoys strong support from the local, provincial and national government. There is equally significant support from the automotive industry and its service providers.

The South Africa's Automotive Supplier Park is modeled as a replica of existing supplier parks in the United States, Japan and Germany. ASP is strategically located in close proximity to major OEM plants including BMW (3.3 km), Nissan/Renault (1.3 km), TATA (0.5 km) and

Skills program name	Exit outcomes (Award type: National Certificate)
1. Introduction to Change Management	Apply knowledge of self & team in order to develop a plan to enhance team performance
	Investigate & explain the structure of a selected workplace or organization
	Identify internal and external stakeholders
2. Problem Solving—PDCA	Recognize areas in need of change, make recommendations & implement change in the team, department or division
	Set, monitor & measure the achievement of goals & objectives for a team, department or division within an organization
	Build teams to achieve goals & objectives
	Optimize manufacturing & production processes
	Prepare & communicate a productivity improvement plan for a functional unit
3. Quality Management	Recognize areas in need of change, make recommendations and implement change in the team, department or division
	Set, monitor and measure the achievement of goals and objectives for a team, department or division within an organization
	Build teams to achieve goals and objectives
	Apply & continuously improve company policies & procedures
	Improve the effectiveness & efficiency of qty. mngt. system
	Create, maintain & update record keeping systems
	Monitor, assess & manage risk
	Manage customer requirements/needs & implement action plans
	Manage & improve communication processes in a function
4. Total Productive Maintenance (TPM)/Lean Manufacturing National Certificate	Recognize areas in need of change, make recommendations and implement change in the team, department or division
	Set, monitor and measure the achievement of goals and objectives for a team, department or division within an organization
	Build teams to achieve goals and objectives
	Optimize manufacturing and production processes
	Evaluate current practices against best practice
	Prepare & communicate a productivity improvement plan for a functional unit
5. Introduction to TPM and Quality Further Education and Training Certificate	Explain the contribution made by own area of responsibility to the overall organizational strategy
	Discuss Just in Time (JIT) and Lean Manufacturing
	Maintain records for a team
	Monitor and control quality control practices in a manufacturing/ engineering environment
	Participate in a task team in a process environment

Skills program name	Exit outcomes (Award type: National Certificate)
6. Introduction to Cleaner Production Further Education and Training Certificate	Explain the contribution made by own area of responsibility to the overall organizational strategy
	Employ a systematic approach to achieving objectives
	Demonstrate an understanding of manufacturing, principles, methodologies and processes

Table 3. Training curriculum (abridged), Tirisano productivity development program.

Ford/Mazda (35 km). Thus far, this is the only supplier park in the world to have more than one OEM in close proximity and this makes it significantly special. ASP clusters automotive component manufacturers, suppliers and service providers in one location to achieve synergies and cost savings.

AIDC is saddled with the responsibility of managing the facility under the Gauteng Growth and Development Agency. AIDC develops factories to lessee requirements on a long-term lease basis. Furthermore, when fully in operation, it intends to offer shared mini-factories for smaller operations and offices for automotive service providers. Tenants under the ASP will benefit immensely because of the benefits that come with shared infrastructure and services. The facility is expected to contain all the relevant training equipment to support specialized training programs relevant to OEMs, automotive component manufacturers, aftersales support centers, dealerships, informal vehicle maintenance sector and unskilled individuals out of school, but interested in specialized skills.

ASP training program focuses on key areas where competence is currently lacking. These include mechatronics, autotronics, programmable logic controllers (PLC), computer numeric controllers (CNC), welding, spray painting, vehicle aftermarket service and maintenance and a variety of training programs to be delivered through the classroom, specialized workshops and PC training. The training model through blended learning approach makes it unique and gives it an edge over conventional approach. Some of the unique features include a Learner Management System (LMS), start-of-the-art simulator for welding and spraying and a vehicle assembly line which will be a typical replica of the actual vehicle assembly process.

AIDC has signed agreements with numerous higher education institutions to develop programs in areas with significant industry demand. The Manufacturing, Engineering and Related Services Sector Education and Training Authority (MerSETA) in conjunction with other institutions, have developed full range of accredited programs to upscale skill level in the automotive industry [8].

AIDC has also collaborated with Ford in developing multiple incubation centers within the Ford facility in Gauteng Province of South Africa, and the managers of these facilities develop top leadership skills within the incubation years. The incubation centers serve as an ideal grooming center for both new employees and older once because there is full conformance to

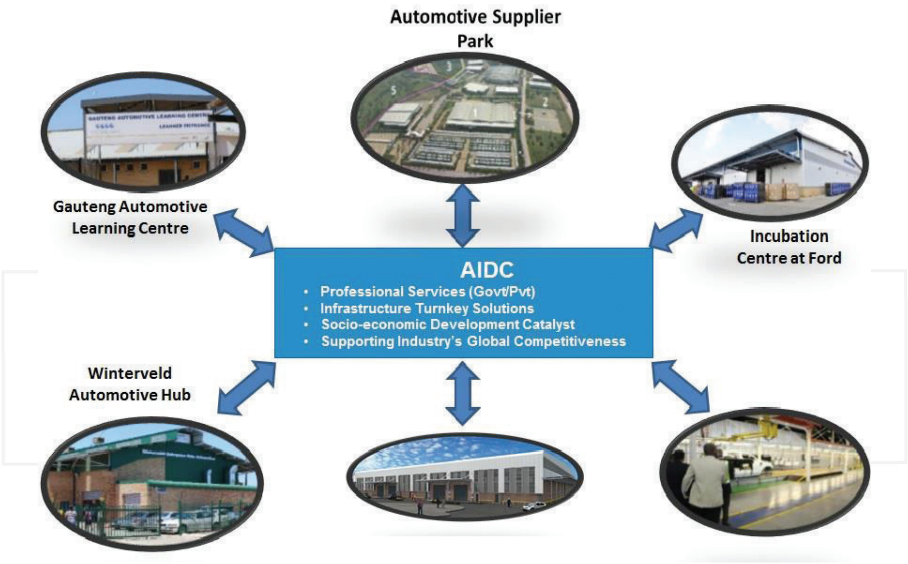

Figure 1. AIDC's footprint in South Africa.

ideal manufacturing conditions, safety procedures, world class processes and manufacturing principles. **Figure 1** shows the footprint of AIDC.

Education and training providers have become increasingly under pressure to improve their programs and to respond to the needs of various employers and learners. As such, AIDC gained a full status as an Employment and Skills Development Lead Employer (ESDLE) in 2004, according to the provisions of the Department of Labor. Furthermore, AIDC has developed training units to establish linkages between industries and specific accredited FET colleges in South Africa.

3.2. International Labor Organization (ILO)/United Nations Industrial Development Organization (UNIDO)

Tier2 suppliers in the South Africa automotive supply chain are generally assumed to be less competitive than Tier1 companies and their global counterparts. Many productivity and competitiveness programs have predominantly focused on Tier1 companies and to a less extent of Tier2 and lower suppliers. There is a distinct gap between Tier1 and Tier2 and lower suppliers with regards to productivity and competitiveness. Resulting from these, in 2015, the United Nations Industrial Development Organization (UNIDO) in conjunction with the International Labor Organization (ILO) collaborated on a study that assessed the competitiveness within the South Africa automotive supply sector with the intent of using the outcomes for strategic planning to help strengthen the sector to enable it achieve a globally competitive position [11].

The aim of this first phase was to establish a supplier needs assessment framework with regards to productivity improvement, resource efficiency, process and technology upgrading, skills, employee engagement and safety in production. The results from this needs assessment informed a baseline survey which eventually inform the joint ILO and UNIDO supplier development approach.

The findings from the study exposed the predominant gaps such as employee engagement, problem solving, adherence to health and safety and strategic training needs. Selection of the companies was done by the guideline received from Automotive Supplier Chain Competitiveness Initiative (ASCCI), which was used by ILO and UNIDO experts to preselect companies to be assessed. Pilot needs assessments were undertaken in four companies in Gauteng jointly by UNIDO and ILO experts in order to test the assessment methodology, perceive responsiveness of firms and align UNIDO's and ILO's assessment frameworks.

The study utilized separate structured questionnaires for UNIDO and ILO. The ILO questionnaire covered the following focal areas: productivity, labor relations and compliance, communication, performance measurement using Key Performance Index (KPI), Research and Development (R&D), product development, Health Safety and Environment (HSE) compliance and competitiveness. The UNIDO questionnaire covered the following focus areas: company policy management, daily management of the production process, process improvement, quality management system, maintenance management and safety, health and environment (HSE) management.

Based on the combined assessments, a joint methodology was developed which was based on the ILO-SCORE training model and the UNIDO-TIRISANO training model. The developed training structure is expected to address skill gaps at the lower tier enterprises when eventually rolled out, because of its multifaceted curriculum.

3.3. Hyundai approach: case study on automotive skills development in Korea

According to Dong-Min and Choi [9], Hyundai Motor Company (HMC) Korea, adopted an innovative blended learning program in 2003 for successfully developing its high-potential managers. HMC introduced an education program (Future Global Leader Program). Future Global Leaders Program was designed to stimulate and groom high-performing junior managers to emerge future skillful leaders. HMC had worked in partnership with Educasia to integrate instructor-led online learning into a program that was previously conducted entirely in the classroom. As a result, Hyundai was able to deliver an expanded learning curriculum in a more efficient and engaging way [9].

Based on Don-Min and Choi [9], HMC focused on developing specialized expertise in five distinct fields namely: human resources (HR), finance and accounting, marketing, operations management and technology management. The program commenced in 2002, and it consisted of five specialized tracks focused on strategic fields identified by HMC.

The Future Global Leaders Program consisted of weekend classes (Friday and Saturday) for 10 months, conducted at local universities within Korea. For each of the specialized fields, the courses were delivered through lectures and discussion groups. The survey conducted upon completion of the course identified the need for a common foundation skills curriculum because of the varying backgrounds and job differences among the participants. The challenge associated with work-learning balance was also evident. The difficulty in balancing work and learning schedules placed a heavy burden on the course participants because of the 2 days they always need to be off work weekly. This resulted in the call for more flexible schedule, more practical experiences and less theoretical-oriented program. Furthermore, the participants wanted an improved learning experience with opportunities to interact with other companies during the program [9].

The feedback received from the first year program informed the considerations adopted in the second year of the program. There was a transition to blended learning in the second year and the program improved by integrated a common business foundation' curriculum at the beginning of the program. As such, registered participants were first taken through common curriculum before advancing to specialized knowledge areas. The program was phased and the first 6 weeks of training were exclusively through online classes on general management principles, followed by a day physical contact at HMC, in which half day went to lectures and the other half was dedicated to testing the knowledge of participants from previous classes. Subsequent class sessions remained well spread-out for strategic learning using the blended approach [9].

3.4. Opel approach: case study of automotive skills development in Greece

Brinia and Pefanis [12] investigated the views of the employees of GM Hellas, a subsidiary of Opel car manufacturer in Greece, concerning the training they receive from their employer. More specifically, the research sought to examine two types of training aspects; those related to the principles of adult education and those related to the business goals of the company. Opel provides in-house training programs to all staff levels and job positions (sales marketing, consultants, technical, service advisors and other departments). The in-house training is often made compulsory because employees are trained on various subject themes. Due to the mandatory training structure, employees are left with little or no choice to participate in the trainings because they are bound by their employment contracts and need to be in full alignment with the managements' training decisions.

The ultimate goal of the training given to employees of GM Hellas is to transfer the philosophy of the organization to its workforce. Based on significant changes recorded by the management upon completion of the training program, the company believes its training helps participants progress, so as to achieve optimal personal development. The trainings are perceived to help Opel manufacture, distribute and support top quality vehicles [12]. Opel maintains a robust training department within GM Hellas, called GM Academy, and each Opel dealer employs a training manager [12]. Within GM Hellas, there are three levels of training namely: bronze (lower level), silver (medium level) and gold (high level). At least 25% of all job holders in each type of post (car sales, spare-part sales, technical advisors, technicians and others), need to have acquired the gold level, whereas the rest should have acquired, at least the bronze level [12].

"The program has three types of training: Training with a trainer (IBT), which was the most common type of training representing 79% of total Opel training sessions in year 2010, web-based training (WBT, 10%) and training in a virtual classrooms (VCT, 11%). All GM

Hellas employees are obliged to participate in training. However, there are several differences, regarding training opportunities among various jobholders: technicians and sales representatives are more likely to receive training (37% of trainees were technicians and 21% of trainees were sales people), rather than directors of all departments (8%) or technical consultants (18%)" [12].

3.5. The India case study

Rishikesha and Jha [13] in their research explored the importance of industry–academia collaboration to build a strong innovation system for economic beneficiation. The India case study under review is an excerpt from the study carried out [13]. The study examined the nature of collaboration between industry and academia in the Indian automotive sector. Based on the study findings, the most prevalent form of collaboration between industries and the academia is competency development and training, while the second most dominant collaboration involves research services such as material testing, product testing and analytical services [13].

The establishment of industry-institution collaboration was seen to be influenced by many factors at the firm level and institutional level. At the firm level, the factors that positively impact the level of industry-institution collaboration are: research and development passion of the firm, level of research and development currently in place, size of the firm and openness of the firm to collaboration [14].

Collaboration and linkages worth noting exist between the automotive industry and higher institutions/research centers. For example, the Advanced Steel Processing and Products Research Center (ASPPRC) had a close linkage with the Colorado School of Mines. Leading global steel makers and automobile companies like TATA and Mahindra were part of this, because the collaboration afforded them information on current innovation in terms of steel processing which in turn influence their manufacturing processes, material selection and automobile designs.

Automotive Skill Development Council (ASDC) is Indians leading council that promotes collaborative skill development program in the automotive sector. ASDC has taken pioneering steps toward the development of occupational standards within the automotive industry. For this purpose, ASDC has been engaging the entire automotive industry in India in order to make skills development an enabler for the sector's growth. The councils mandate is to create an enabling environment that ensures availability of required numbers of skilled manpower that meets the quality expectations of the automotive sector. A Memorandum of Understanding (MOU) exist between the government of India, and one of the leading auto manufacturers, Tata Motors, to help promote the skill development centers across its six plants in India. The corporate partnership of Tata Motors with ASDC is a step toward reaping India's demographic dividend by enhancing employability within India as well as in other countries and also contribute to government's aggressive plans under the Skill India Mission. The collaboration is expected to promote the ASDC certification that will create career paths for those interested and currently employed in the automotive industry. The training modules cover designing, manufacturing, automobile production, sales and service in various support functions with a focus on quality.

3.6. The Indonesia case study

Indonesia is the largest economy in South East Asia and the automotive sector is one of the largest industries in Indonesia ranking 15th globally in terms of auto sales. The industry has enjoyed steady domestic sales growth, with sales forecast that shows it will continue to grow until the end of the decade. The Indonesian automotive has become prominent among automotive cluster in South East Asia [15]. It is an example of globalization (regional clusters of interdependent firms) and hybrid production (a global initiative that was adapted to customary local conditions) [15]. Japanese multinational enterprises (MNEs) have invested in Indonesia because of its proximity to favorable resources, which is a key lesson from the Indonesian automotive cluster in terms of regional economic development. According to Irawati [15], to develop into a mature cluster, there are four recommendations and lessons that can be learned, but the forth is most important to this study because of its obvious skill development component [15]. The recommendations includes: building clusters in developing countries, exploiting MNEs' own clusters and networks, exploiting geographical proximity for networks and technology and upgrading companies in the Indonesian automotive cluster.

3.7. The Thailand case study

Despite increasing educational attainment across all levels in Thailand, the Ministry of Education's push to increase vocational education, the quality of institutions remain a concern with many firms reporting that these graduates, despite going further in education, are still not well-prepared for the labor market. Individuals, particularly poor and vulnerable populations, may also acquire work-readiness skills through non-formal education. In 2014, The Ministry of Education increased compulsory education to 12 years of schooling. This will allow more students from the lower quintiles to meet firms' minimum education requirements, and trends.

Thailand's "Automotive Industry Master Plan 2012-2016", aimed to administer integrated sustainable automotive human resource development projects emphasizing on training, curriculum development, lecturer development and promoting in-house training centers to accelerate human resource development throughout the industry. Furthermore, the master plan emphasize on creating a collaborative effort with education institute to prepare students for their future careers in the automotive industry.

The aim is to empower human resources in the automotive industry by enhancing their knowledge, skill and ability. Automotive Human Resource Development Project (AHRDP) in collaboration with Japan enabled the transfer of crucial technologies and standard emphasized on developing the body of knowledge which consists of program and expert training in four areas to enable industry-wide development in order to support the growth of Thailand's automotive industry. To achieve desired excellence in human resources development, the emerging guidelines sought to formulate human resource development plan for automotive industry to formulate a long-term plan. It was designed to survey data and design standard academic and continuous professional development (CPD) curriculum with academic cooperation from domestic and oversea institutions together with the private section to develop and improve curriculum in order to satisfy present and future industry demands. Also, it was planned to develop an automotive human resources development (AHRD) operating work system to develop human resources at all levels, specifically for supervision, testing and research purposes, by integrating all entities involve in automotive human resource development toward sustainable development of the automotive industry. The guideline is expected to add to the body of knowledge for further development.

4. Conclusion

Skills shortage within the automotive industry is not exclusive to the South Africa automotive sector. Other countries have experienced same in various forms across unique lines and need areas. The measure adopted in addressing the knowledge gaps is simply the variance. Retention of skilled manpower is one of the challenges identified in the South Africa automotive sector. This chapter discusses skill shortages relative to the skills development interventions by various stakeholders within and beyond the South Africa automotive industry. From the study, the major solution to remedy low competence is continuous skills transfer through highly structured cross functional skill development programs, which have been widely discussed in this chapter. Social factors which may be part of the reason for poor retention of competent employees was not considered. For further studies, social factors and gratification measures for skilled employees retention is worth considering.

Blended training and virtual teaming [16] have been widely adopted for training purposes. Original Equipment Manufacturers and lower tier suppliers have realized the effectiveness of blended learning approach. Through this methodology, employees have the opportunity of engaging in both hands-on and computer-based learning. Scheduling flexibility is a major advantage this method have other approaches. Based on the study, sufficient evidence confirms the shift and upgrade from conventional training methods to blended learning approach. Blended training is indeed an excellent approach for delivering both short-term and most especially, long-term courses.

In South Africa, specialized courses for the automotive sector have been accredited by the Department of Higher Education and Training (DHET). This was facilitated through the linkage created by the Gauteng Automotive Learning Centre, in collaboration with the Automotive Industry Development Centre (AIDC). These programs are set to create career paths for employees within the automotive industry. Shop floor employees can aspire and work toward skills development in both technical and non-technical areas. This platform is a plausible channel through which employees may grow over time and eventually accomplish their career ambitions. Registered employees will go through series of specialized courses designed to progressively take them through a formal learning path. The courses are expected to be fully available from 2018 academic session, and offered through the University of South Africa (UNISA), the largest distance learning institution within the African continent. Statistics of employee retention and employee turnover over the next few years, will be key indicators to determine how well academic engagement influence labor retention.

Collaboration between industries and intermediaries cannot be overemphasized. This chapter shows that collaboration is essential, and various collaborative efforts employed by various stakeholders within the automotive industries have been discussed. Recognized Technical and Vocational Educational Training Colleges (TVET colleges) and Further Education and Training Colleges (FET colleges) all have a part to play in developing skills for the industry. Due to continuous technological changes and industry innovation, training curriculums need continuous upgrade. Failure to upgrade will result in increasing skills shortages in the industry.

Cross functional training is crucial for flexibility in the workplace [17]. Cross training has been a useful knowledge management tool for creating and transferring technological knowledge within an organization. Organizations adopt cross training, job rotation systems, work flexibility and teams in an attempt to manage process changes due to technological upgrade and market forces [18]. The South Africa automotive industry has long realized this and cross training is promoted by training intermediaries within the industry. Contrarily, smaller industries are yet to come to terms with this and employees end up specializing only in specific areas, hence, limiting their adaptability to other areas where totally different skill sets are required. As such, cross training should be encouraged and recommended for process units within the shop floor and associated functional areas.

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Chapter 5

Designing and Developing New VET Curricula to Address Skills Gaps in the Aeronautics Industry

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Additional information is available at the end of the chapter

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Abstract

Aeronautic industry is one of the enablers of the economic development and social insertion at European level, and it is one of the drivers of expansion of remote regions as far as it allows habitants, workers, and companies at these regions to expand their activities and areas of influence. The European aeronautics industry, including the commercial air transport, generates more than 220 billion of Euros and more than 4.5 million of jobs. These figures are expected to be double by 2030. Future developments in the sector, together with greater intra-European mobility of workers and population aging, bring a greater need for new skills in the work force together with an urgency for a larger number of professionals. Therefore, to achieve the desirable sustained growth the EU needs to invest in high-quality VET (vocational education and training) in order to be able to supply the AI (aeronautic industry) with qualified workers. VET stands for education and training which aims to equip people with knowledge, know-how, skills and/or competences required in particular occupations or more broadly on the labor market. This work discusses the outcomes of the AIRVET project, an European partnership whose principal objective is the development and promotion of "curricula and VET courses" in the Maintenance and Information and Communications Technologies (ICT) domains, required for a highly skilled aeronautical workforce.

Keywords: vocational education training (VET), aeronautic industry, skills needs/skills gaps, curricula, multimedia resources

1. Introduction

As was recently discussed at a UK Education and Skills meeting organized by the Royal Aeronautical Society, the financial importance of the aerospace industry to the European economy is significant [1]. The aviation industry is estimated to be worth 4.5 Trillion dollars by 2030 [2], and Airbus forecasts that in the period 2014–2033, approximately 31,000 passenger aircraft are required at a value of $4.6tr [3].

Aeronautic industry is recognized by the high-level skilled professionals it engages [4]. Main job positions involve engineers and maintenance technicians trained at the highest level. However, studies [5] show that 85% of its direct employment is concentrated in 5 EU countries, and the aging of EU population threatens the availability of qualified personnel, emerging in skill shortage sector. Some of the most important industry's problems today are related to skills gaps in current employees as well as the requirement to attract more people into the industry [6].

The industry is constantly developing technology to improve aircraft performance and the efficiency of the operation of airports and aircrafts. This need for a growing number of trained personal can be further seen in statements made by most of the large aviation companies, such as Airbus that: "… has a proactive approach to working with Universities around the world to support the development of future talent. This includes implementing strategic programs such as the Airbus University Board as well as engaging with relevant academic and student networks" [7].

To achieve the desirable sustained growth, the Aeronautic Industry highly depends on the availability of flexible and high-skilled labor force. The overall performance of Aerospace education and training must be improved and a balance between initial and continuous education and training has to be established [8].

2. Designing and developing new vet curricula to address skills gaps in the aeronautics industry

EU needs to invest in high-quality vocational education training (VET) in order to be able to supply the aeronautic industry (AI) with qualified workers [9]. EU aeronautics industry needs to be considered as a global industry rather than a national one, and mobility of workers is undeniable. A close cooperation among VET systems from different EU countries is also desirable to cope with the demands of the growing aeronautical industry:

- enhancement of the global outcomes of the learning process;
- collaboration between European VET providers and training systems;
- equilibrium between vocational training activities along the workers life; and
- effective application of knowledge and skills independently whether they have been learned in official and non-formal contexts.

The AIRVET (aeronautic industry skills resolution for a more efficient VET offer) project is a long life learning initiative financed by the European Commission to prepare industry and society to face challenges identified hereafter.

Its main objective is to **design**, **develop**, **evaluate** and **disseminate adapted/new AI curricula and VET courses** in the specific fields of maintenance and information and communications technologies (ICT).

The main results expected by AIRVET are:

- Identification of training and **regulatory** frameworks, and **training gaps and opportunities** for the development of VET curricula and training initiatives.
- **Design of curricula and multimedia resources** for training based on innovative ways of delivering VET, e.g., learning-based games, 2D/3D graphics, low cost simulations, virtual reality, etc.
- **Delivering the curricula by developing pilot runs,** practical learning sessions in which the dynamic solutions will be tested in order to collect opinions from both the trainers and the participants on the educational programs and innovative learning approaches.

2.1. Phases and activities

AIRVET is implementing a series of activities and producing outputs for different target groups. The work plan has three main phases, summarized in **Table 1**, and includes open channels of communication through online tools and a series of events to assess the projects product with stakeholders of the industry and to disseminate the project. Project phases, outcomes, and events are summarized in **Figure 1**.

Phase	Main output	Short description
Analysis of skills needs	Territorial analysis	Collection of training needs involving the stakeholders of the sector
Curricula design	AI training curricula	AI maintenance and ICT training curricula/program
Curricula delivery	Multimedia resources	Multimedia resources for training (minimum 3) + user's guide manual

Table 1. Phases for VET improvement.

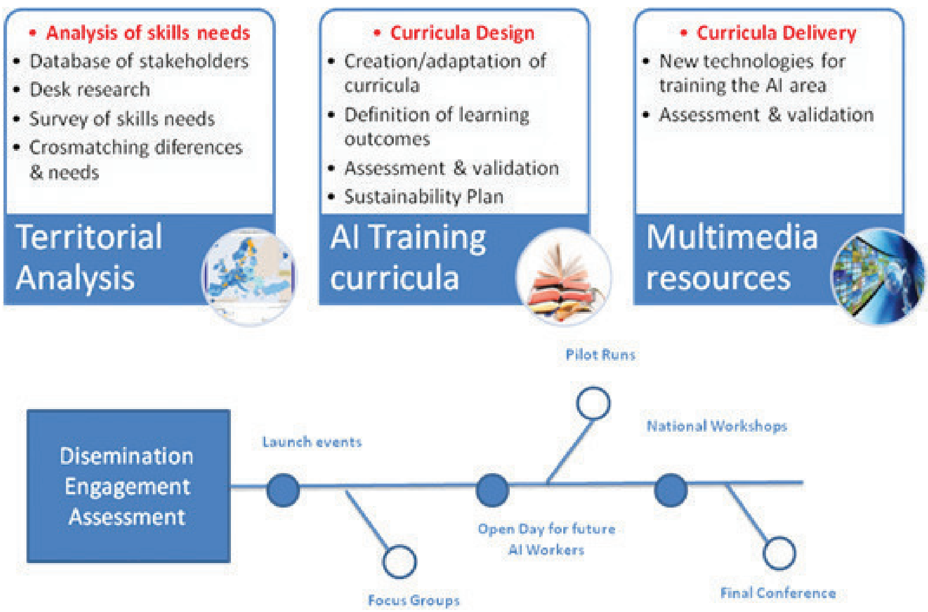

Figure 1. Phases, outcomes, and events of the AIRVET initiative.

3. Territorial analysis of skills needs

The initial outcome of the project has consisted in an extensive work to identify the training and regulatory frameworks, as well as the training gaps and opportunities for the improvement and development of VET curricula and training initiatives [10].

The methodology undertaken aimed to identify potential areas of training gaps, curricula that need to be developed or updated or training materials, where improvements could be achieved. The work carried out to investigate these issues, named "Territorial analysis," was split into three components, as illustrated on **Figure 2**:

- **a desk study** to identify and analyze the current VET programs offered in the airline industry in Europe and determine the principal EU regulations that structured the training in the aviation industry and identify skill gaps;

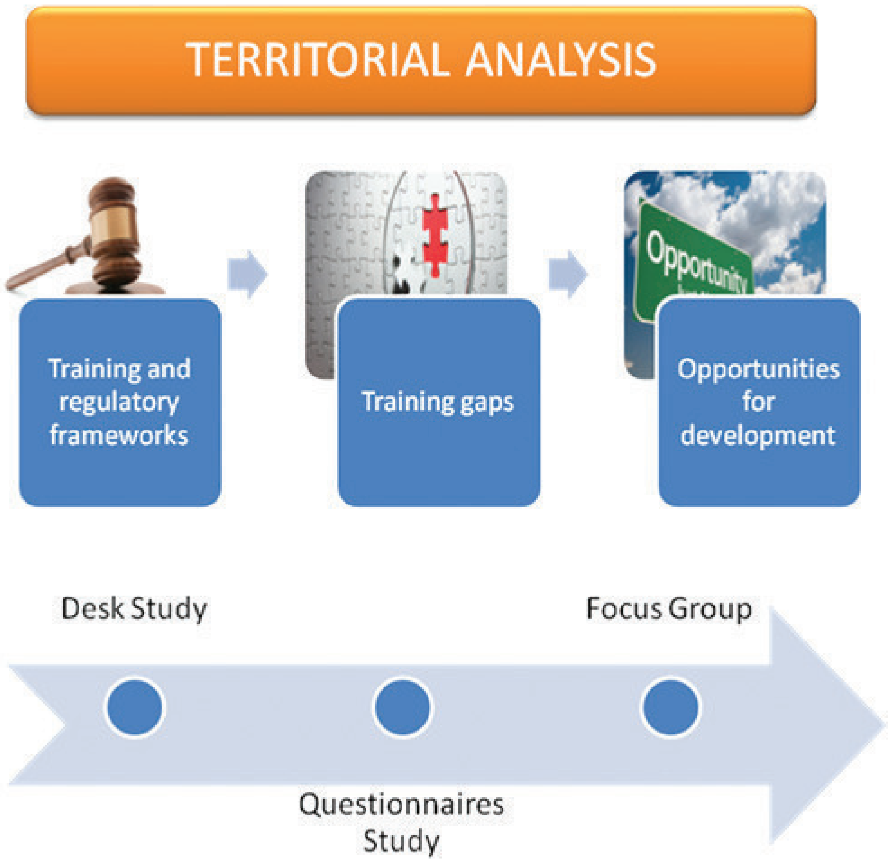

Figure 2. Phases of the Territorial Analyses of skills needs.

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- **a questionnaires study** to sought views directly from practitioners to obtain information on their views of skills needs and skills gaps, current training available, and methods of training delivery;
- **a focus groups** on skills needs study to foster face-face discussion among agents in the aviation industry using the preliminary results obtained from the desk research and questionnaire analysis.

3.1. Desk study analysis

The desk study was wide ranging and addressed many aspects of the aviation industry including air traffic management, airlines, and airport operations. It has brought the following conclusions:

- The **training of pilots and air traffic control personal** and **Cabin crew training** are highly regulated and supplemented by frequent in-house training. There was no evidence of skills gaps, which was expected in these high safety critical roles.
- For **airport operations**, although there are several international bodies that promote and endorse aviation training, there are also many roles that require unregulated training that is carried out by the airport companies. In many countries, especially those without a large aerospace industry, there are few opportunities for people to find out about the career opportunities within airports. This gap leaves potential employees uninformed about the opportunities available. The creation of **open-source training materials that could be used outside of an airport training centre may be beneficial** in increasing recruitment but also providing new employee's basic knowledge of how an airport operates.
- **Manufacturing skills** are normally obtained via an apprenticeship and countries usually have their own defined systems. It is not clear what additional training companies deliver and they rarely publish information on specialized courses they operate. The gap mainly discussed in the literature is the lack of new entrants. **Materials to inform and enthusiasm the youth to engage in apprenticeships** would be beneficial.
- The training of the **people who maintain aircrafts** is regulated at EU level. It is unlikely that this project could influence the training undertaken, but it could **produce materials that can be used to enhance training, an example being for those opting to carry out self-learning.** There were some skills gaps identified for specific aircraft types that are not common and for the new technology of electric driven aircraft.

3.2. Questionnaire study analysis

To perform the questionnaire study, stakeholders were subdivided into four categories as shown in **Figure 3**. The questionnaire was bespoke designed, as indicated in **Table 2**, considering each stakeholder group characteristics [11].

3.2.1. Survey circulation and response

An intensive survey questionnaire distribution campaign was put in place to maximize its circulation across the European aviation industry and to ensure a wide range of aviation

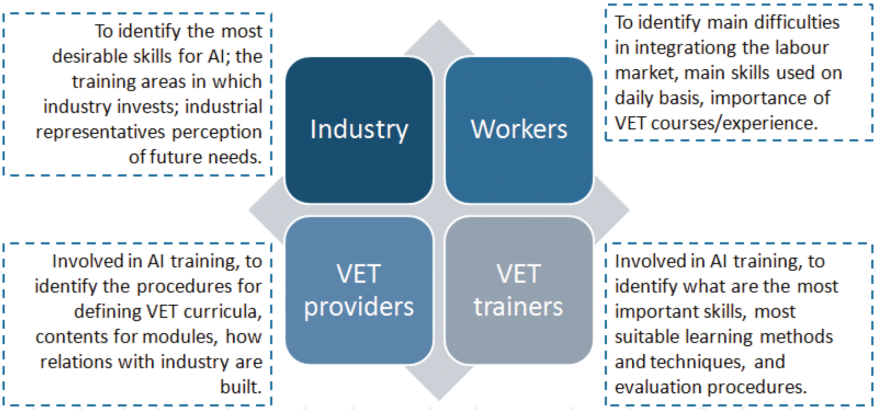

Figure 3. Stakeholder categories and specific survey areas.

Question categories	Workers	Industry (managers)	VET providers	VET trainers
Demographics				
Company background	Operating country Company size Workers role	Operating country Company size Company function	Operating country Aerospace activity	Operating country Aerospace activity
Worker background	Age Work experience Education background			
Current training information				
Training related to soft skills	Training experience	Training provision	Courses run	Courses run
Training related to technical skills	Training experience	Training provision	Courses run	Courses run
Training delivery method (tradition, CBT, blended, etc.)	Training received and preferred		Training provided	Training provided
Skill gaps and training development				
General areas of skills gaps	Training needed	Skill gaps identified	Skill gaps description	Skill gaps description
Future skills gaps identification and training development	Preferred training delivery method	Future skills gap description	Course development drivers	Course development drivers

Table 2. Set of questions pose to the different groups.

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industry workers and professionals reaction. Population been reached by the questionnaire distribution campaign it was roughly around 16,500 persons distributed as summarized in the **Table 3**, distinguishing among "**primary readers**" (persons directly reached) and "secondary readers" (resulting from circulation of the survey inside companies and institutions).

Survey demographics summarizes how the distribution of responses obtained from EU countries varied by stakeholder group. The greatest number of responses was obtained from the industry workers (81%), while 19% of the responses were received from industry mangers. Responses from VET providers and trainers were very similar. Although only two responses were obtained from UK VET providers, these were from the Aviation Skills Partnership (ASP)

Distribution medium	**Primary readers**	**Secondary readers**	**Global targets**
AIRVET Website	1000 Estimated figure through the number of visits on the web page		1000
Direct email approaches	2085 2085 emails were sent		2085
Paper copy distribution	200 Rough figure (people without access to the online questionnaires, meetings with aerospace personal, conferences and exhibitions		200
Social media	300 Estimated figure through the number of followers on social media		300
Professional organizations	Details of the AIRVET project and a request to complete the questionnaires were circulated by professional organizations such as:		
	The Chartered Institute of Logistics and Transport (UK) magazine bulletin 1030 It was distributed to all members (approximately 1030) readers.	1500 [12]	2530
	The Institution for the Development of Vocational Training for Workers (Italy) (published in the EuroGuidance newsletter) 617 members	10,000 [13]	10,617
	A stand at the "Futures Day" at 2014 Farnborough Airshow EU training organizations represented	320	352
Total number of targets reached by the questionnaire survey information	**Primary readers**	**Secondary readers**	**Total**
	5264	**11,820**	**17,084**

Table 3. Population reached by the questionnaire distribution.

and SEMTA, which are the two key bodies. The majority of responses were obtained from the partner countries (95% of the responses). Response rates in France, Portugal, and the UK were fairly even (6–9%), while responses from Italy were slightly higher (12%). The majority of responses from industry workers and managers were from people working in large companies with greater than 200 employees (39% and 59%, respectively). Representation from small companies was only 11% and 10%.

Responses from both, the workers and managers survey indicate coverage from at least a dozen aerospace sectors (**Figure 4**). Interviewed VET providers and trainers, 67% of respondents indicated that more than 50% of their training was carried out in the aerospace sector.

Based on industry data [14], it was concluded that the proportion of responses between managers and workers obtained through the questionnaire was similar to that existing within European companies. In European industry, the distribution between managers and workers accounts to approximately 7% managers and 93% workers. In the survey, the results show that the 12.5% of the people asked were managers and the 87.5% of them workers.

Nevertheless, the survey could give a bit-biased overview of the whole industry because there were countries with a strong aerospace industry, like Germany, France, or United Kingdom with little representation in the survey, and countries with a weak aerospace industry with have had a larger representation in the responses, like the case of Poland (see **Table 4**).

In other terms, according to the responses obtained in the questionnaire concerning worker's qualification, 74% of people who answered the questionnaire have a university degree, 14% have college education, 6% school education, and 6% other. When comparing this to the actual situation of the industry, in the European aerospace sector, the percentages are quite different. Only 38% of workers have university education, while 41% of them have technical education and 21% have other education.

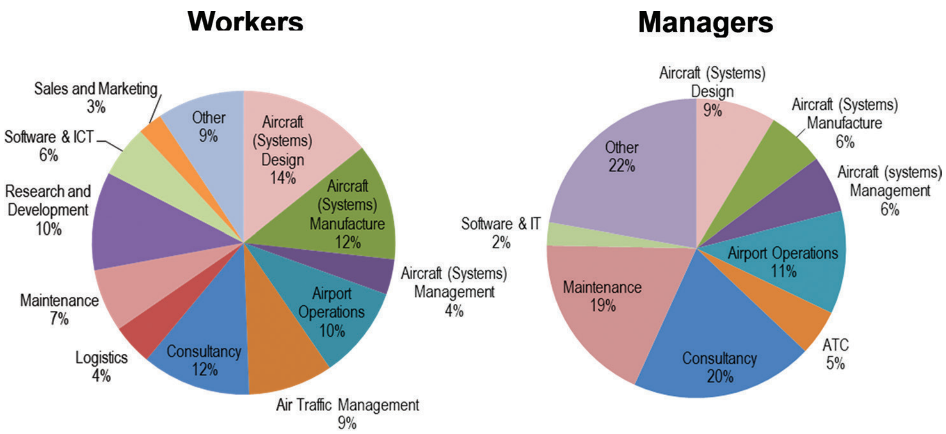

Figure 4. Distribution of aircraft industry companies responding to survey.

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Country	Respondents	% of total	×1000 employees in the sector	% of total
The Netherlands	3	0.58	15.77	3.14
Spain	86	16.57	38.13	7.59
France	20	3.85	143.2	28.49
U.K.	35	6.75	103.78	20.65
Poland	200	38.53	14.05	2.80
Italy	24	4.62	41.6	8.28
Portugal	30	5.78	5	0.99
Germany	6	1.16	95.08	18.92
Sweden	1	0.19	8.25	1.64
Others	114	21.97	37.74	7.51

Table 4. Relationship between weight of responses obtained and real participation of labor force in the aeronautical industry by country.

3.2.2. Training experiences

The majority of aircraft industry workers have attended job's related training courses in the last 3 years (96%). Of these training events, workers reported that 48% were in subjects related to soft skills and 52% in technical areas as illustrated in **Figure 5**.

Of the soft skills training received, the highest reported area was health and safety (20% of courses attended). Team working, communication skills, data protection, general, project, and risk management were the next popular and ranged between 7 and 12% of courses. This distribution was very similar to that provided by the management, with 13% of the courses provided in health and safety and team working, communication skills, data protection, general, project and risk management each accounting for 8–11% of provision (see **Figure 6**).

Training in soft skills is delivered by both VET providers and trainers. However, while 43% of courses delivered by VET providers are in soft skills, only 32% of courses delivered by VET trainers are in soft skills, as can be seen in **Figure 7**.

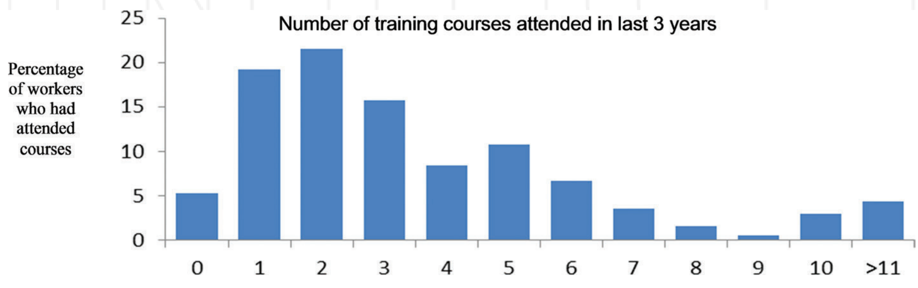

Figure 5. Number of training courses attended by workers over the last 3 years.

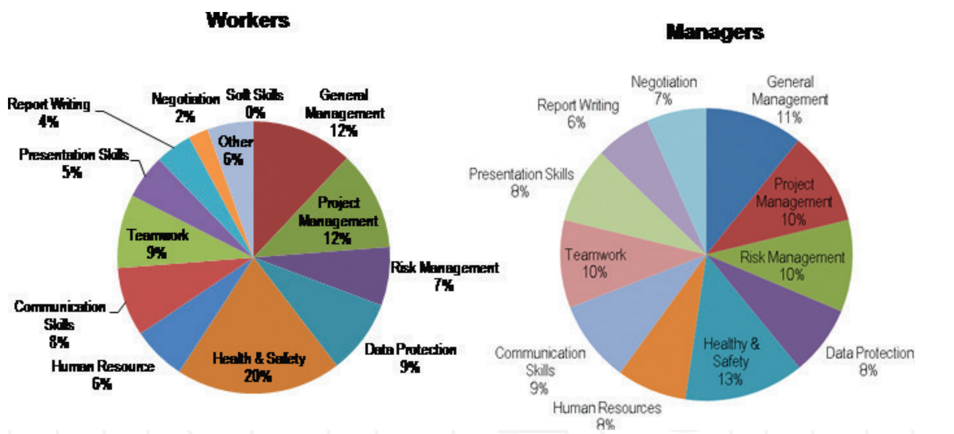

Figure 6. Distribution of soft skills training courses attended by workers and provided by managers.

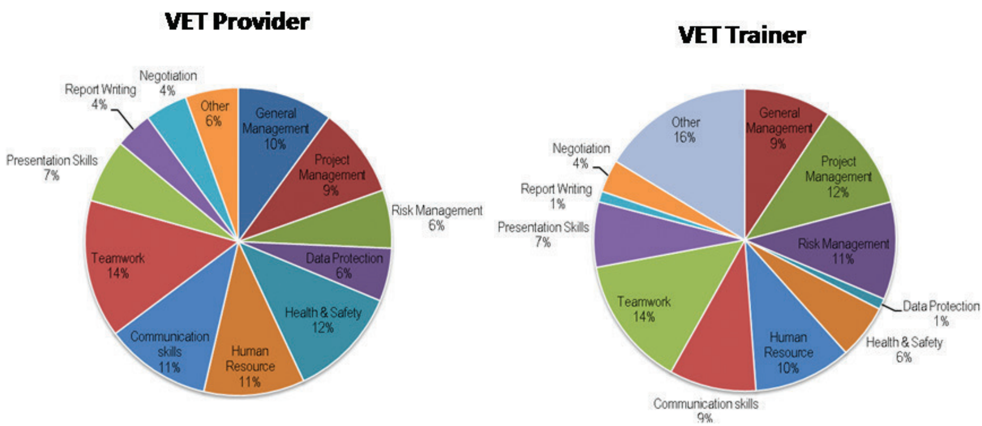

Figure 7. Distribution of soft skills training courses provided by VET providers and VET trainers.

Technical skills courses attended by industry workers were fairly evenly distributed across the categories surveyed, as can be observed in **Table 5**. Courses related to safety, security, and human factors were most frequently attended. This was reflected by the training courses being provided by management.

The distribution of courses delivered by VET providers and VET trainers in technical skills are shown in **Figure 8**. Course provision was rather evenly distributed across the categories surveyed. Aircraft regulation and maintenance accounted for a major percentage of courses provided (19% providers, 22% trainers). In terms of specific subjects, human factor training was the largest provision in both groups (providers 11% and trainers 9%).

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Technical skills	Total number of courses undertaken by workers	Total number of courses offered by management
ICT maintenance/logistics services	51	15
Workshop practice	56	30
Human factors	95	45
CAD/CAM	22	31
Stress analysis	29	28
Aircraft design	45	10
Cargo handling systems	20	13
Aerodynamics	32	19
Airport emergency procedures	43	31
Aircraft ground handling systems	26	26
Airport/aircraft regulations	66	41
Aircraft maintenance procedures	38	35
Aircraft maintenance equipment	25	29
Air traffic control	55	25
Aircraft manufacturing	20	15
Airport operations	44	31
Airworthiness	46	39
Research and development	43	24
Safety	105	54
Security	51	46
Other	62	

Table 5. Technical skills training courses provided by industry management and attended by workers.

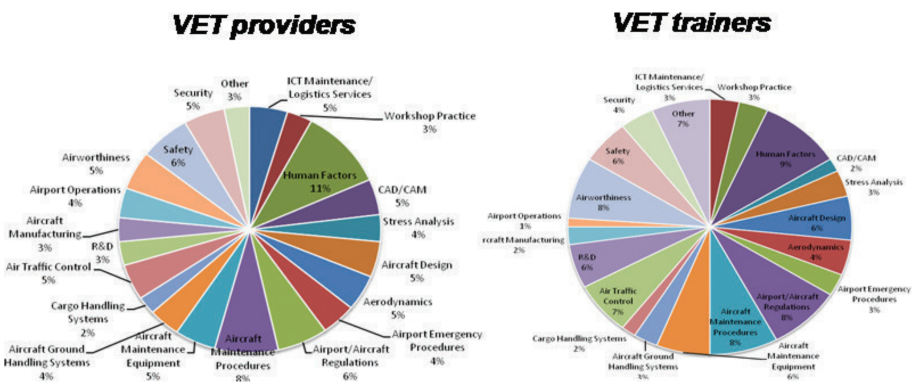

Figure 8. Distribution of technical skills training courses provided by VET providers and trainers.

3.2.3. Current possible skills gaps: Identification and training development

The areas of training gaps identified by the managers are shown in **Figure 9**. The top four pre-defined list categories are:

- ICT maintenance/logistics.
- Airport emergency procedures.
- Air traffic control.
- Ground handling systems.

The skills gaps results shown in **Figure 10** identify the subject areas where VET providers and VET trainers have emphasized the need for training materials. The majority of VET providers believed there is a requirement for maintenance equipment and ICT documentation with an equal percentage for the other common themes.

The majority of VET trainers identified human factors as the most significant subject area. ICT maintenance and ATSEP were mentioned in several areas including air navigation and baggage handling indicating the diverse interpretation of this term.

In addition to asking the four groups what they thought were current and future skills gaps, the VET providers were asked what the drivers for the development of new courses were. **Figure 11** shows that the majority of the training development (42%) is influenced by requests from the customer/industry. The next largest driver is market research (18%).

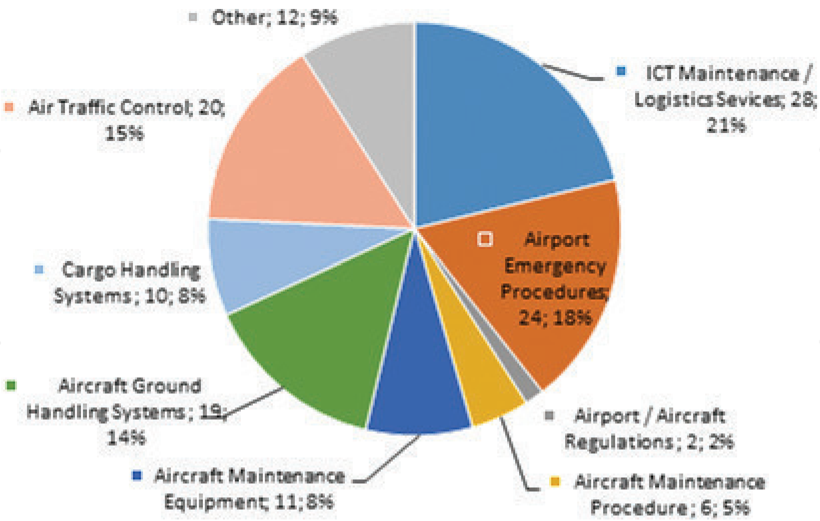

Figure 9. Areas of current skills gaps identified by industry managers.

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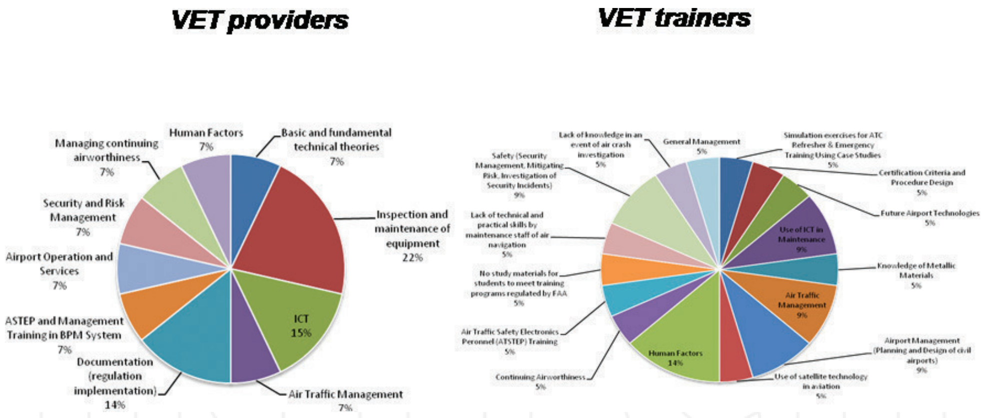

Figure 10. Areas of current skills gaps identified by VET providers and VE trainers.

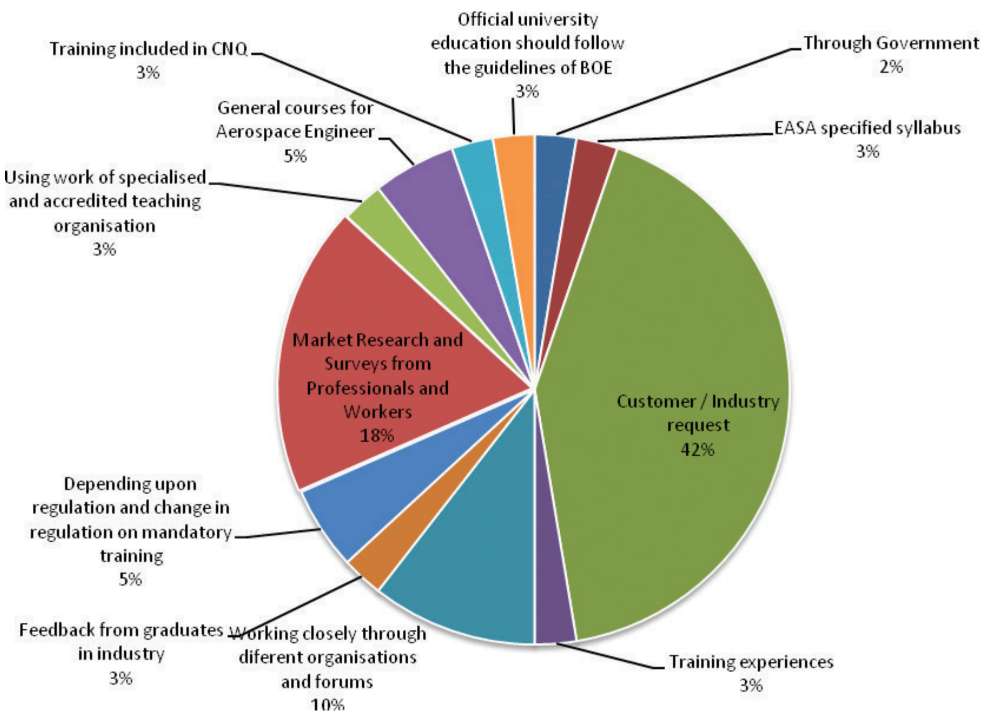

Figure 11. Drivers for the development of new courses as identified by the VET providers.

Both VET providers and trainers indicated that resource issues (manpower, money, lack of time and lack of expertise) were the main reasons why courses were not developed in areas where they had identified gaps (**Figure 12**).

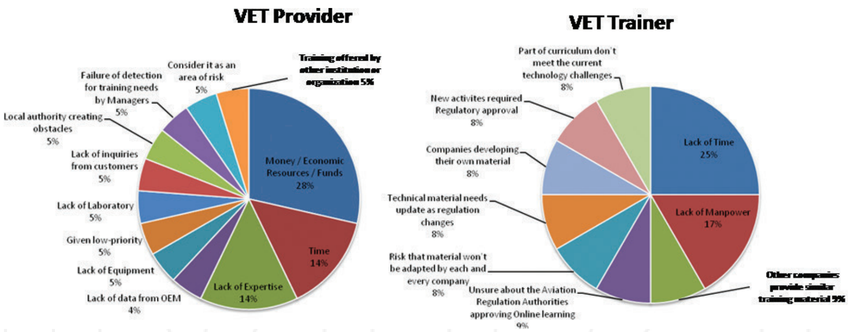

Figure 12. Reasons identified by VET providers and VET trainers why courses are not developed.

3.2.4. Summary of training requirements

The most frequently identified skills gaps are summarized in **Table 6**. The first column lists eight general skill gap areas that were most frequently identified. The second column highlights specific topics within these categories. There is some repetition of ATSEP, but this is included and illustrates that certain topics do not fit neatly into a single category.

Skills gap opportunities	
Aircraft ground handling	Baggage/Cargo handling systems Carriage of dangerous goods ATSEP (Air Traffic Safety Electronics Personnel) training for BPM (baggage handling)
Aircraft structural maintenance	Composite material Repair of aircraft structures (composite repair) Repair of aircraft structures (metallic repair) Nondestructive testing/Inspection of new composite materials
RPAV/UAS (remotely piloted air vehicle)	Air traffic control/integration with normal air traffic New national/European legislation (particularly with regard to RPAV) Single European sky legislation Performance based navigation
SMS (Safety Management Systems)	Training on SMS for aeronautical industry (CAP 760 implementation: FMECA, HAZOP, Event Tree methods) Aerodrome certification and Safety Management Systems: ICAO Annex 19 Risk Assessment techniques: identification & mitigation
Maintenance of specific Airport Operations	ATSEP (Air Traffic Safety Electronics Personnel) Training Maintenance and Inspection of equipment for Edge (light controls) Maintenance and installation of airport/runway lighting (CAP637 implementation: obstacle lighting & marking / aeronautical ground lighting)
Aircraft operation	Flight dispatch optimization (optimization of the scheduling of aircraft maintenance for items not part of the MMEL)
Aeronautical industry introduction	Key concepts and drivers in the aeronautical industry (could be airline, airport or aircraft driven). Provide new workers with introduction.
Human factors	

Table 6. Summary of frequently identified skills gaps (according to the questionnaires results).

The main drivers for the development of new courses are meeting the needs of industry and the regulatory bodies. Currently, most courses are taught using traditional methods; however, the workers identified a desire for blended and practical-based delivery. Among the principal skill gaps, safety and human factors were often underlined.

3.3. Focus group study analysis

The focus groups **generally confirmed that the gaps identified** as part of the desk study and questionnaire analysis do exist. They also introduced some **new areas of skills gaps**. As result they inferred that:

- The main gaps identified with existing employees are associated with the less regulated sections of the industry and airport operations.
- Soft skills as management, communication, presentations are mentioned frequently as an area where further training is needed in the workforce.
- Human factors become a topic of interest, even more in connection with safety applications.
- Remotely piloted aircrafts or unmanned aircraft systems, was acknowledged as an emerging topic with increasing knowledge demand.
- Problems in recruiting skilled staff and the need to make youngers aware of job prospects are clearly recognized as upsetting.

3.3.1. Main findings on training and skills gaps

Potential skills and training gaps have been identified in the following areas:

- **Airport operations**: creation of open-source training materials that could be used outside of an airport training center may be beneficial in increasing recruitment but also providing new employee's basic knowledge of how an airport operates.
- **Manufacturing skills** are normally obtained via an apprenticeship and countries usually have their own defined systems. The gap mainly discussed in the literature is the lack of new entrants, therefore materials to inform and enthusiasm the youth to engage in apprenticeships were considered beneficial.
- **Regarding maintenance**, beside the high level of regulation, the production of materials that can be used to enhance training, an example being for those opting to carry out self-learning was considered beneficial; as well as the training the use of practical tools and methods and techniques to achieve the administrative, planning, and time management burden especially in a more electronic world. Also, some opportunities were found for enhanced training material to compliment the available texts and support learners with material constructed around the modular syllabus defined in EC 1149/2011. Annex III, Part-66, App I.
- A developing subject area, for which a future need is anticipated, is training for **remotely piloted aircraft systems**. There is very little official training presently available, and the topic is still being debated in terms of the levels of EU regulation.
- A training area that is growing in demand, and for which there is not much provision is **Air Traffic Safety Electronics Personnel** (ATSEP).

The project team decided that three subject areas should be explored in terms of developing/adapting training curricula and developing multimedia training materials in the second year of the project:

- **Maintenance**: a proposal was made to produce stimulating multimedia materials from some of the chapters included in the EASA maintenance basic license curricula, such as contents on helicopter aerodynamics, propulsion, and human factors.
- **Ground operations:** this broad subject area was highlighted in several pieces of work and by several countries, and gaps have been identified in the working knowledge of how an airport functions and how the various roles interact. The training currently undertaken has a significant vocational element. Most of the suggestions addressed knowledge required for increase safety and awareness of hazards at work, as well as human factors issues.
- **Human factors:** human factors was a topic of interest in all the phases of the study, including literature review, questionnaires, focus groups, and interviews. This theme has strong implications for maintenance workers and ground operations staff.

Human factors was nominated as crucial to familiarize new workers with the operation of an airport; to stress potential occupations and to give youth and public a closer outline of the aerospace industry.

4. Curricula design

One of the objectives of AIRVET was to produce a curricula bespoke to fill the skills gaps identified in the project and to complement the training offer inside the aviation domain [15]. The territorial analysis delineated four VET areas within the EU aeronautical industry that might benefit from enhancements [16]. All of them could be approached from the human factors perspective. Implementation of the human factors topic to address these areas is summarized in **Table 7**.

Target audience	Training need	Comments
Maintenance technician	Improvement in the teaching materials and soft skill development	Improve the training materials of the Human Factors module in the Part 66 approved training manual
Airport operation operatives	Up skilling and induction of workers to address skills/training gaps and improve operation safety	Provide exposure to human factors to address skills gaps. Short introductory course to the topics
Human factors as part of an induction for new workers	Awareness training of the subject and its importance	Its importance on the development of safety awareness and safety systems. The vehicle used to support the development of the other three areas
Future workers	New training material	Provide introductory training materials for future workers who have had no exposure to the subject or the "Aviation Culture."

Table 7. The 4 areas identified for development of training materials that utilizes human factors.

Course title	Purpose	Course length	Module developed	Module length
EASA Part 66 maintenance course and human factors	Course is not changed, but module 9 on human factors has been developed to include planning and time management	Typically 2 years	Human factors in aircraft maintenance	50 h
Human factors in airport operations for new workers	An induction course for new workers comprising 5, 1 day, modules	1 week	An introduction to human factors in airport operations	8 h
Human factor awareness training for managers	Design of a module to support VET providers in developing an introductory human factors course for managers	As defined by the VET provider	Human factors in Airport Management	50 h
Airport industry introduction course	A short course, comprising of four modules, to attempt to enthuse young people about possible careers within an airport environment	1 day	Human performance and limitations	90 min

Table 8. A summary of the four courses and modules developed.

A summary of the four courses and the associated human factors modules are shown in **Table 8**. As it can be seen human factors are a common subject in each course, although the four courses target a different set of the aviation industry's employees, and the courses and learning resources have been developed for each target audience. The approach taken ensures that the training materials developed can be fully utilized by the target audiences and where necessary, complies with the EU aviation regulation framework.

The work required to design the curricula was split into a number of activities to ensure that the aims of the project were met (see **Figure 13**). The creation of the curriculum for each of the four training courses required the definition of course:

- A module is a separate unit of instruction. A course will be made up of a number of different modules, with each module covering a different topic area. Each module description contains detailed objectives, learning outcomes, indicative content, details of assessment, and resource requirements.
- A learning object is a short multimedia based training session [17]. They will correspond to a total of 2 h of multimedia presentations complemented with guidelines on how the training material can be implemented.

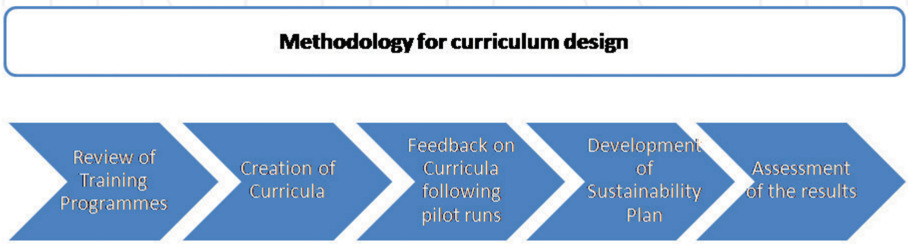

Figure 13. Strategy/methodology for curriculum design.

- A course descriptor is a document that defines the course and includes descriptions of the learning objectives and modules, besides other generic information about the course.
- Course documentation provides an overview of the course, the teaching approach and its component modules.

4.1. Curricula delivery

The curricula delivery aimed to produce new training materials around human factors topics for distinct target groups to meet the needs of the areas identified in the project and to provide trainees with a sufficient understanding of the value that human factors knowledge. The audience is made up of people that are not experts of what human factors is about; mainly students/future workers, maintenance technicians, and airport operations workers.

The AIRVET e-learning training materials includes four curricula, three learning objectives, and nine lessons, plus a detailed description of the multimedia materials developed highlighting contents, format, and target audience; including a manual for users to assist trainers in the use of the materials in the training courses. All materials are available in English, French, Italian, Polish, Portuguese, and Spanish.

Figure 14 provides details about the main topics and related sub-topics composing the AIRVET training materials. The lesson start with a story or a case study, includes exercises test the user's knowledge, and at the end of the lesson, a screen "Lesson learnt" display a list of the key concept to remember (see **Figure 15**). **Figure 16** presents some examples of the training units.

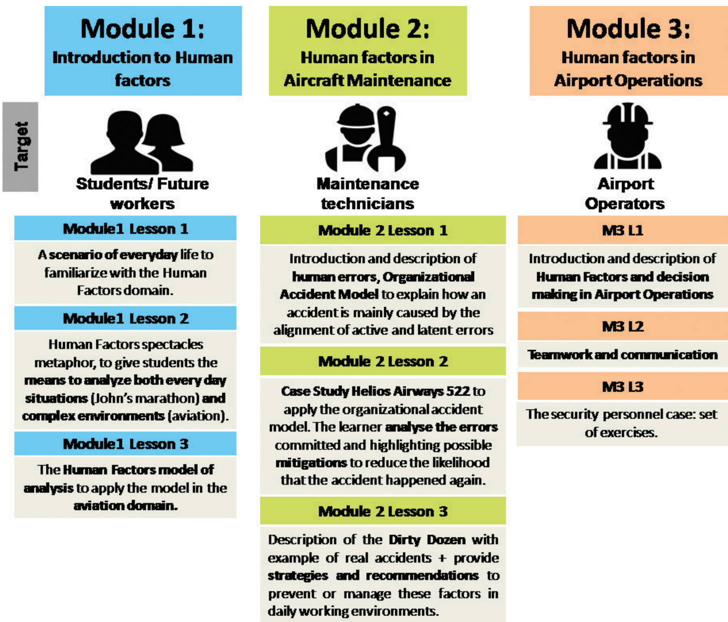

Figure 14. AIRVET e-learning materials.

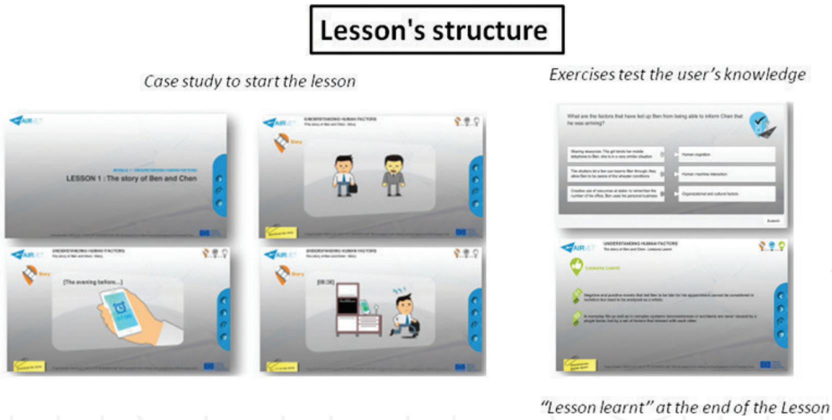

Figure 15. Lesson's structure.

4.2. Evaluation of the new multimedia on line training programs

Quality and effectiveness of the multimedia courses and materials become a key issue to guarantee the success of a training program specifically oriented to meet industry needs in regard to human factors skills and knowledge among its future staff [18]. The evaluation of this training program is therefore concerned with the determination of change in the student behavior and the change needed in the organizational structure where the student will be immerse [19]. Hence, training must be evaluated in this case as the process of developing skills, habits, knowledge, and attitudes for the purpose of preparing students for future positions and maximize their effectiveness [20]. To evaluate the effectiveness of such a process, some authors [21] have adapted a popular organizational training evaluation framework, the Kirkpatrick's four level model of training criteria [22], to the assessment of educational effectiveness in higher education.

Figure 16. Screenshots of a training unit slide (module 2).

Additionally, the assessment of HF training programs is particularly problematic because the difficulties in measuring effective improvements in human factures performances with standard test, such as motivation, social interaction, innovation, pride of work, etc. Kirkpatrick's model have also demonstrate in the past its suitability for summative evaluation of human issues programs [23].

Kirkpatrick model foundational principle is "The end is the beginning." Its philosophy is focused first on the desired results and second on the conduct required to achieve them. In that regard, instructors must identify the skills, knowledge, and attitudes that will result in the wanted performances.

The ultimate defy would be to build up a training package that aids the participants to absorb the knowledge they need and also to enjoy from the training program. Kirkpatrick is based on four stages evaluation procedure. The four level model consists of reaction, learning, behavior, and results criteria.

The project has organized pilot runs at four countries to test the learning materials. Pilot runs consist of a practical learning sessions in which the "dynamic" solutions developed (training materials) have been tested by trainees and workers in aerospace industry, and opinions from trainers and participants on the educational programs and innovative learning approaches have been collected. Pilot runs events have been held in four different countries: Spain, Italy, France, and Poland.

These pilot runs are essential to collect opinions both from trainers and participants on the training programs and innovative learning approaches, so the alliance can readjust them accordingly. More than 150 attendees have participated in the assessment. **Figure 17** summarizes the pilot run realized by the project.

Pilot Run exercises				
Module 1: Learning object: Understanding Human Factors		Module 2: Learning object: Human Factors in Maintenance		Module 3: Learning object: Human Factors in Airport Ground Operation
Poland June2015	**Italy** June 2015	**France** September 2015	**Italy** June 2015	**Spain** September 2015
47 participants	34 participants	30 participants	6 participants	17+ 66 participants
Young graduates and new AI workers	Students and young graduates	Young graduates and new AI workers	Maintenance Experts and AI professionals	17 Airport and HF experts and AI professionals 66 Young graduates /new AI workers in the airport domain

Figure 17. Pilot run exercises.

5. Conclusions

This paper illustrates the attempt made by AIRVET project to synthesize both current training needs and skill gaps in the aerospace industry, particularly at six European countries: Italy, France, Portugal, Poland, UK, and Spain.

To accomplished this objective the project performed a desk study, questionnaires from more than 500 people, interviews with managers and focus group with experts. The project attempted to triangulate the results to establish clear areas that would benefit from the development of vocational training.

The project have also identified and discussed the principal regulations that govern training syllabi and the skills gaps to cope with continuously evolving technologies. All those skill gaps can be tackle through well-planned lifelong learning programs. It was also indicated the benefits of better communications resources such as multimedia materials to revitalize education or broaden knowledge spreading.

From the desk research, a lack of information on skills gaps with employees was found. Many subject areas have been suggested as having skill gaps. Health and safety were the most relevant need that came out from the questionnaires, followed by human factors, safety systems, and management. The skill gaps were confirmed by the focus groups.

Soft skills were regularly cited as an area of concern for new entrants and also for current staff. One of the explanations of this need is that while technical skills are learned through formal training, it is not the case for soft skills that are mostly acquired through experience and not formal training.

Three subject domains were identified to be explored in terms of developing/adapting training curricula and developing multimedia training materials in the second year of the project:

- **Maintenance**: considering the 17 modules in the EASA "basic license," topics can be identified that could be used to produce exciting multimedia presentations: Module 12 on helicopter aerodynamics, Module 14 on propulsion, and Module 9 on introduction to **human factors**. In particular, this last topic has been **highlighted throughout this study as one where employees need additional education**. Improved training package for self-learning and additional materials for trainers and providers are envisage

- **Ground operations**: gaps have been identified in the working knowledge of how an airport functions and how the various roles interact. This gives an opportunity to develop and test learning materials. Most of the suggestions addressed knowledge required for increase safety and awareness of hazards at work, as well as human factors issues. These suggestions were aligned with a **human factors program** for ground operations.

- **Human factors**: human factors were a topic of interest in all the phases of the study, including literature review, questionnaires, focus groups, and interviews. This subject has **clear applications in maintenance and ground operations**. **It is worth concentrating on the production of human factor training materials which can unify our project and reach across subject areas and careers**.

The project has focused its efforts of developing training materials in the area of human factors. It has produced and validated four courses and nine e-learning lessons, all available in English, French, Italian, Polish, Portuguese, and Spanish.

The analysis of skills needs was used to develop and/or adapt training curriculum, including the definition of learning outcomes along with assessment and validation activities. Training materials with multimedia resources have also been developed and assessed. Additionally, the project has adapted a popular organizational training evaluation framework, the Kirkpatrick's four level model of training criteria, to the assessment of human factors multimedia training programs in aerospace engineering higher education. Pilot runs at 4 countries to test the learning materials. More than 150 attendees have participated in the assessment.

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