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MASTER THESIS

ANALYSIS OF THE PRINCIPALS OF CIRCULAR MANUFACTURING COMPARE TO LEAN MANUFACTURING

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INDEX

INDEX OF ILUSTRATIONS

1. INTRODUCTION

1.1. ABSTRACT

The purpose of the Final Master Thesis deals with the study of two types of organization systems: Circular Manufacturing and Lean Manufacturing, both with great utility and importance to achieve the desired objectives in the sustainable development goals for the world but that still they do not have a great importance because they are not so developed.

It contains a brief introduction on Circular Manufacturing, with its advantages and difficulties and measurement indicators, and on Lean Manufacturing, to later compare the two and see what their similarities, differences and overlaps are in order to have a better understanding for a possible merger between the two systems.

1.2. OBJECTIVE

The purpose of this project is the completion of the Final Master Thesis to obtain the Master in Engineering in Industrial Technologies of the ETSII, specialized in management engineering, at the "Politécnico de Valencia" and also in the "Politecnico di Milano", carried out by the student Alberto Cervera Estañ.

In this document, has been addressed the analysis of the concepts of circular manufacturing and Lean manufacturing, for having a better understanding which are the common things and the difference that they could have.

1.3. BACKGROUND

This Thesis is driven by the choice of my tutor, Sergio Terzi and I, to have a better knowledge about the Circular manufacturing and Lean manufacturing. Nowadays, there is not much information about the comparison of both and the possibility of having these organization systems coalesce, that's the reason why we have chosen this topic.

1.4. MOTIVATION

The motivation of this work is to finish the study and procedure of the Final Master Thesis, to be able to demonstrate my knowledge learned throughout the course and thus, be able to finish the Master and start working in PWC next year.

The choice of this Department to carry out the project is due to personal interest in the subject and thus, be able to capture all the knowledge learned in it. On the other hand, the type of topic chosen for this project comes from the hand of my tutor who believes is a good theme for the Thesis.

1.5. FRAMEWORK DEVELOPMENT METHODOLOGY

Although the advantages of adopting methodological frameworks are becoming more widely recognized, there is still no precise and exact meaning of what a 'methodological framework' is. A follow-up analysis was carried out, drawing on the systematic literature review which consists of identifying, selecting and critically appraising material in order to respond a clearly articulated topic.

Before undertaking the systematic review, the criteria must be explicitly described in a clear plan and methodology. It is an extensive and clear research that manage several information and database that the student or other academics can replicate it. It entails devising a well-thought-out search strategy that focuses on a certain topic or answers a specific query. Within established timeframes, the review indicates the sort of information searched, criticized, and reported. The review must include the search terms, search tactics (including database names, platforms, search dates…), and limits.

Illustration 1 Systematic Literature Review

I have been searched information in different websites such as Worldwidescience, Google scholar, Refseek… and also articles found by myself in google, using the conceptual method of and/or, until I arrive to the number of 207 articles. Subsequent to this, it has been taken into account different steps for rejecting the articles that were not relevant or were not great for this topic.

The first procedure It has been made is to start rejecting, of all the articles, those that are duplicated which only 16 could be found as a replica, and those that are not articles, books, reviews…, that is to say, declined those that are opinions or questionnaire, which are 8, because it is not known, 100%, if that information is true and verifiable. In this case, the total of articles that has been rejected are 24, therefore they remain as unique articles 183.

The next step to continue discarding candidates and leaving only the abstracts to continue carrying out the elimination process later is to reject due to the title review. To do this, various approaches has been used to discard: the ones that were not relevant, did not comply the search criteria and talked about the subject but applied some business case because it focuses less on the theory of Circular Manufacturing and its principles. In this part, it has been rejected most of the documents, 103, leaving a total of 80 articles.

With the remaining 80, an abstract review has been applied, filtering by field such as Economy, Business… and filtering by key words such as Circular, Lean, Manufacturing… That with the sum of 3 documents that have been entered at the end, a total of 44 studies candidate have been left.

Lastly, all these documents or the important parts of them have been read, in order to make the last selection of the articles and thus be able to start writing the entire thesis about the "Analysis of the principals of circular manufacturing compare to lean manufacturing".

Finally, applying these steps, of the 207 articles that were available at the beginning, only 29 meet the necessary characteristics to be used in the thesis because of the relevant information, and also because the database is having a direct bearing on the field.

In the next picture you can observe the systematic literature review that has been made with everything that has explained above.

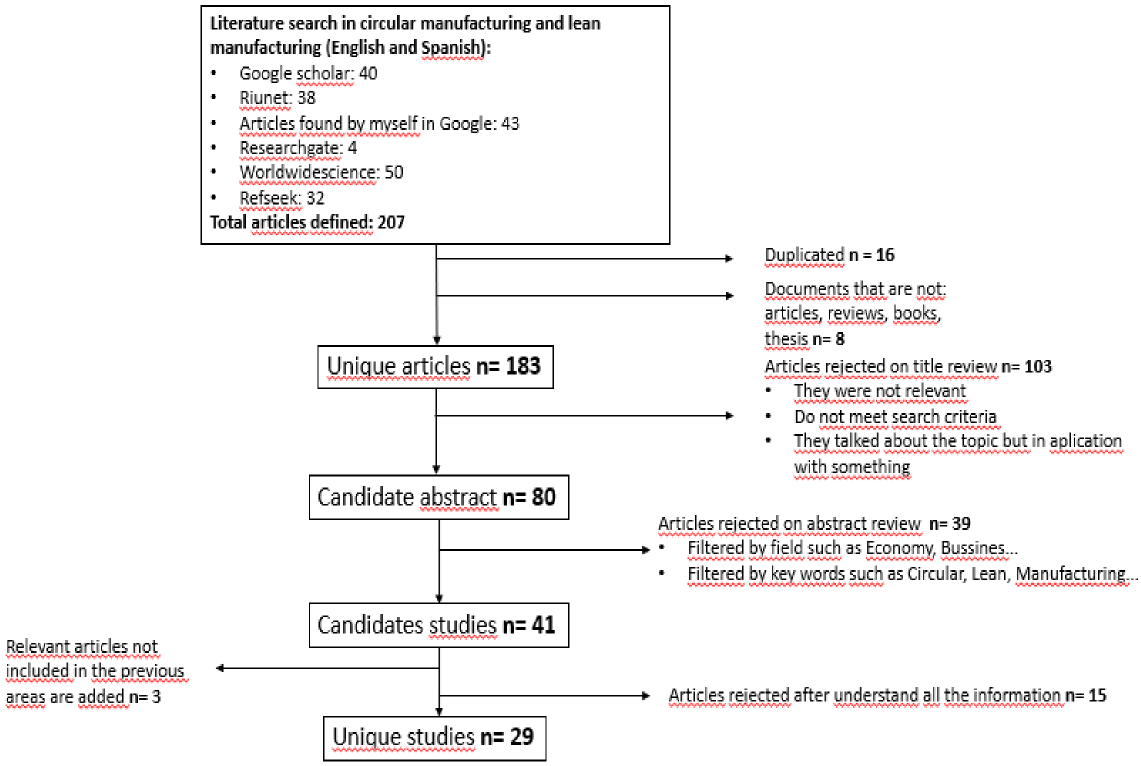


Illustration 2 Framework of the protocol

2. CIRCULAR MANUFACTURING

2.1. ORIGIN

The ideas of trying to reduce and reuse as much as possible the waste of resource and the material that are generated because of the production, have been around for a long time in the industrial sphere.

The notion of circularity has an important historical and philosophical origins. The idea of feedback and cycles in real world systems is old and arises in various philosophical schools. It resurfaced in industrialized countries after World War II, when computer studies of non-linear systems have revealed the complex, connected and unpredictable nature of our world, which is more like a metabolism than a machine [1]. Already in the nineties of the 20th century, a maturity of the concept was reached from different intellectual contributions from various currents and schools of thought. Pearce and Tuner (Pearce and Turner, 1990) were the first to introduce the concept in the late 1980s, according to certain authors.

This new approach implied breaking with the linear economy model extending the life cycle of products; recovering those already used through the concept of reverse logistics; close the useful life of products through the recovery of waste; and rebuild and recover materials, work and energy [2].

At the moment, the Ellen MacArthur Foundation (EMF) has a very significant role in the dissemination and promotion of the circular economy concept, with various tools in different organisms which are assisted by experts on the material and with a high demand.

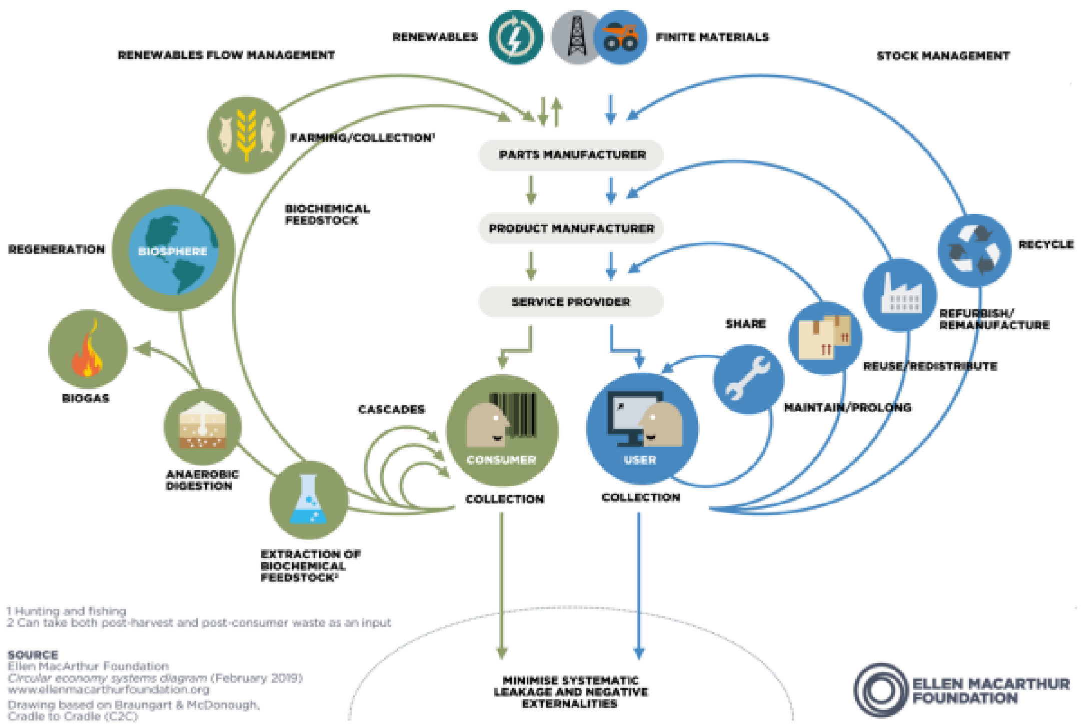
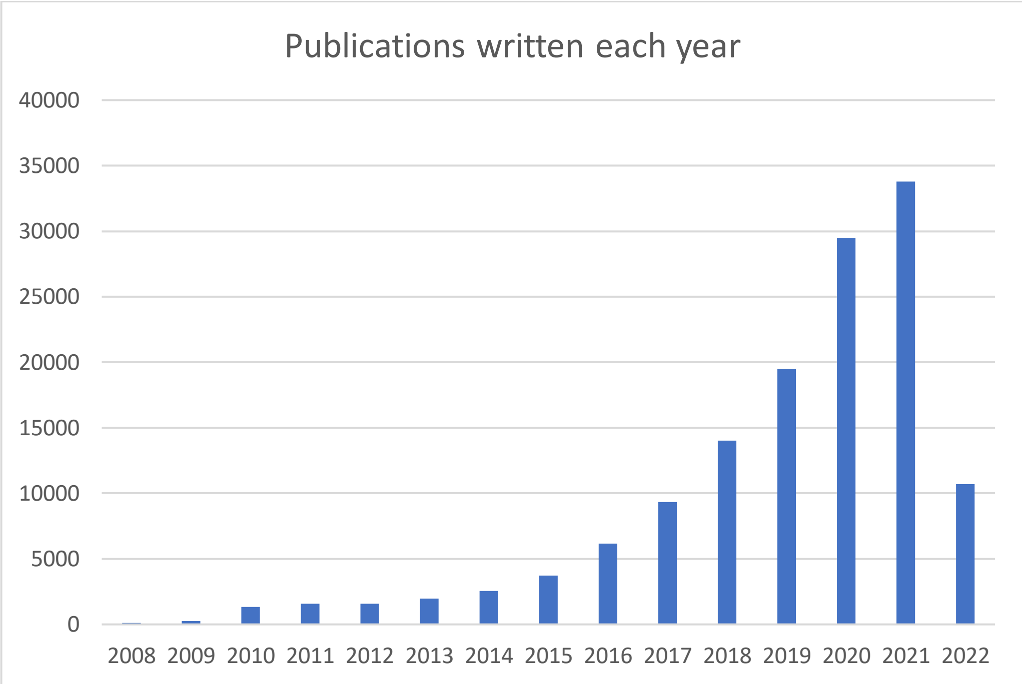


Illustration 3 Circular economy scheme according to the Ellen MacArthur Foundation

However, it is not the only place where we can find some information. With the passage of time, it can be seen how the issue of circular economies is becoming more important, hence there are a lot of authors interested in this topic that have written their articles therefore the number of scripts and tools has increased. To verify this, it has been made a graphic that shows the articles written in each year to see the increasingly of what it has been said.



Graph 1 Publications written about Circular Economy

As a result, it is evident that topic of the transition to a Circular Economy is extremely important.

Not only is the number of research growing, but a huge quantity of companies is boldly displaying their efforts toward more sustainable production. That is the reason why it is necessary to change from a linear model to a circular model and that is explained in the next section.

2.2. CIRCULAR MANUFACTURING TRANSITION

Why it is vital to transition from a linear economy model to a circular economy, are answered in at least three significant tendencies that presents the limits to growth:

- Earth as a food supply, rather than renewable natural resources.
- The ability of the environment to absorb waste and diverse emissions as a negative environmental component of production operations.
- The consumerist way of life found in cities.

Disregard for these constraints puts the survival of people on Earth at jeopardy in the long run and it causes a slew of economic, political and environmental issues in the short term.

2.2.1. LINEAR MODEL EVOLUTION

In the last lustrums, the companies have been used the traditional linear economy which follows the "take-make-dispose" consumption pattern. All this means that supplies are collected, converted into goods, and ultimately dumped as garbage. And the value, for this economic system, is created by manufacturing and selling as many items as the company can.

Illustration 4 The linear Economy

The problem with this is simple: waste. Simply put, in a planet with finite resources, this type of economy system and its proclivity for waste important materials is a serious concern.

Most of the waste that companies produced, is buried or thrown into landfills and that has very negative impacts. To begin with, it implies that precious materials are wasted underground, and it is not the only thing, also may have significant environmental consequences such as polluting emissions. Secondly, that it requires more raw materials from the Earth, as well as basic things like energy and water to manufacture and create the goods. Last but not least, promotes a consumer culture in which the worth of goods, at the end of their useful lives, is undervalued.

In addition, it is no longer just because of the negative impacts mentioned above, but it must also be taken into account that the space we have for landfills is getting smaller and smaller and there will be a point where this solution will not be available [3].

All this implies the necessary change that our world must make, and that is where the new economic system appears so that the problems do not intensify. This new system is called Circular Manufacturing.

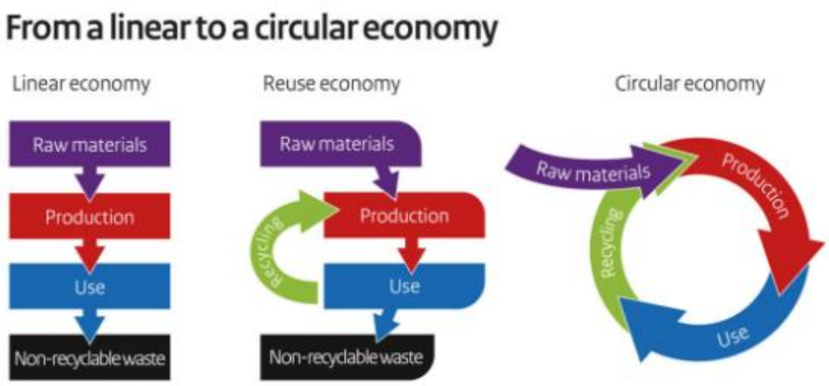


Illustration 5 Linear to circular transition

2.2.2. SUSTAINABLE DEVELOPMENT GOALS

To eradicate the aforementioned problems and to promote sustainable development, governmental institutions, such as United Nations, have expressed an interest in promoting the sustainable production and the rights of the workers.

The UN expresses these objectives with the 17 SDGs 2030 Agenda that is a global call stop, which countries have committed to prioritize progress for those who are furthest behind, to end poverty, safeguard the environment, and ensure that everyone lives in peace and prosperity by 2030 [4].

The 17 sustainable development goals are described in the following illustration.

Illustration 6 Sustainable Development Goals

The transition from linear model to a circular manufacturing aligns with the 17 SDGs. The achievement and progress of the sustainable development goals, stimulates the circular economic model and it is beneficial for this type of economic system. Moreover, the circular economy must be implemented in order to attain these Objectives, therefore these two goals and models are complementary.

Of the 17, there are 5 that could be directly related to the Circular economy:

- SDG 6: Clean water and sanitation.
- SDG 7: Affordable and clean energy.
- SDG 8: Decent work and economic growth.
- SDG 12: Responsible consumption and production.
- SDG 15: Life on land.

Of the five objectives mentioned above, we must also take into account three that are indirectly related with this economic model:

- SDG 1: No poverty
- SDG 2: Zero hunger
- SDG 14: Life before water

These goals would already account for almost half of the objectives involved in the development of the Circular Economy, but also there are six more that could contribute in this model:

- SDG 4: Quality education.
- SDG 9: Industry, innovation and infrastructure.
- SDG 10: Reduced inequalities.
- SDG 13: Climate action.
- SDG 16: Peace, justice and strong institutions.
- SDG 17: Partnerships for the goals.

To sum it all up, of the 17 targets described in the SDGs 14 could be related with the Circular Manufacturing that both pursue social and economic progress while remaining mindful of the planet's natural constraints, and promote the long-term viability of current natural resources [5].

2.2.3. MATERIAL CRITICALITY

Another aspect to take into account when changing from one model to the other is the critical raw materials (CRMs). These raw materials are economically and strategically significant for the European economy, but their supply is fraught with risk, these materials, which are used for various sectors, are not only essential for the industry sectors and future uses, but also for the European economy´s long-term viability.

Illustration 7 Critical raw material

It is known when the raw materials are critical for diverse reasons. To start with they are extremely important for major sectors of the European economy, as mentioned before. Because of their substantial reliance on imports and the concentration of some crucial raw materials in specific countries, they face a high supply risk. Last of all, due to the very distinctive and trustworthy qualities of these materials for existing and future applications, there are no (viable) replacements.

2020 Critical Raw Materials		
Antinomy	Hafnium	Phosphorus
Baryte	Heavy Rare Earth Elements	Scandium
Beryllium	Light Rare Earth Elements	Silicon metal
Bismuth	Indium	Tantalum
Borate	Magnesium	Tungsten
Cobalt	Natural Graphite	Vanadium
Coking Coal	Natural Rubber	Bauxite
Fluorspar	Niobum	Lithium
Gallium	Platinum Group Metals	Titanium
Germanium	Phosphate rock	Sctrontium

Table 1 List of critical raw material

It is necessary to clarify and distinguish that these materials are not described as critical because are considered scarce. They are classified like this for the reasons explained above.

To conclude, the circular economy helps to mitigate the dependency and the high supply risk on the materials, which are in the list, and tries to reuse them for greater sustainability of the Earth.

2.3. DEFINITION AND PRINCIPALS

Previously, it has been commented on the origins of the circular manufacturing and the reasons why this model had to be taken in order to have greater stability and sustainability. But what is the meaning of Circular manufacturing?

The circular manufacturing is a new model of production and consumption that ensures long-term growth. With the circular manufacturing, we support resource optimization, a reduction in raw material consumption, and the utilization of trash, either through recycling or repurposing to create new products.

First of all, the amount of time a resource spends in the inner circles of the stock management should be maximized, that is to say, is better to keep it in the inner circles first and if it is not conceivable, then go through the reuse, remanufacture and refurbishment sequences. After being in the stock management circle, it must be tried to reduce the time of the renewable circle. As a result, the items will spend less time in the reuse process and can be reintroduced into the manufacturing chain as soon as feasible. Furthermore, lowering material, labor, and energy costs would result in a more lucrative system. Illustration 3 depicts all of this information.

As a result, the circular manufacturing aims to make the most of the material resources at our disposal by prolonging product life cycles. The concept is inspired by nature, where everything has worth and is utilised, and trash is transformed into a new resource. For that reason, the balance between advancement and sustainability can be maintained [7].

This model of manufacturing is based on different principles. According to Repsol [7]: The 3R rule, which is crucial for sustainable development and maintaining environmental balance, is well-known to most of us: reduce, reuse and recycle.

- **Reduce**: Change our consumption habits to one that is more environmentally friendly. We avoid the generation of waste and the usage of raw resources by reducing consumption, and thus the environmental impact is reduced.
- **Reuse**: Extending the lives of products by repurposing or reusing them.
- **Recycle**: Encourage excellent waste management and recycle as much as possible as raw material for new goods.

However, thanks to the rise of increasingly ecological thinking, there are four more completing the 7R which are the necessary actions to achieve the change towards a circular manufacturing. These four are: redesign, repair, renovate and recover.

- **Redesign**: Consider and design items in such a way that their production process uses less raw resources, extends their lifespan, and produces less waste (or at least waste that is easier to recycle). This helps to protect the environment.
- **Repair**: Previously, when a product malfunctioned, we tended to replace it. Repairing it, on the other hand, is not only less expensive, but it also eliminates the need of fresh raw materials, saves energy, and produces no waste.
- **Renovate**: Old items should be updated so that they may be used as vintage.
- **Recover**: Give goods that are about to be trashed new life.

Illustration 8 Principles of Circular Manufacturing [7]

2.3.1. OPPORTUNITIES

This model is intended and designed to be regenerative, with the goal of improving resource performance and combating the unpredictability that climate change may bring to enterprises. It offers operational as well as strategic benefits, and it brings together a massive potential for value creation opportunities across the economic, business, environmental, and society realms [8].

2.3.1.1. ENVIRONMENTAL OPPORTUNITIES

- **Fewer greenhouse gas emissions.** The circular economy has the potential to reduce greenhouse gas emissions because this model employs renewable energy which is less damaging in the long term than fossils fuels, residues are regarded as valuable and are absorbed to the greatest extent feasible so that they can be reused in the process or because energy-efficient and non-toxic materials will be prioritized, as will manufacturing and recycling techniques [9].

  According to the Ellen MacArthur Foundation, a circular economy development path in Europe could reduce carbon dioxide emissions by 48% by 2030, or 83% by 2050, compared to current levels (48% reduction in carbon dioxide emissions by 2030 across mobility, food systems, and the built environment). Furthermore, according to sector-specific analyses, the United Kingdom could cut greenhouse gas emissions by 7.4 million tonnes per year by keeping organic waste out of landfills.

- **Primary material consumption.** When compared to today, a circular economy development path could result in a 32% reduction in primary material consumption (measured by car and construction materials, real estate land, synthetic fertilizer, pesticides, agricultural water use, fuels, and non-renewable electricity) by 2030 and a 53 percent reduction by 2050.

- **Land productivity and soil health.** Land degradation costs the global economy an estimated USD 40 billion each year, not including the hidden costs of increased fertiliser usage, biodiversity loss, and the loss of distinctive landscapes. The value of land and soil as assets will be enhanced by increased agricultural production, reduced food waste, and the return of nutrients to the soil. The circular economy reduces the need for extra fertilizer replenishment by transporting considerably more biological material through the anaerobic digestion or composting process and back into the soil. Using accessible organic waste in a systematic way might help rejuvenate land and replace artificial fertilizers 2.7 times over. Synthetic fertiliser usage may drop by as much as 50% if Europe adopted a circular economy approach to food systems**.**

- **Reduction in negative externalities e.g., congestion time**. Externalities such as land usage, air, water, and noise pollution, hazardous material discharge, and climate change would be managed in a circular economy. The circular approach, for example, would benefit households by lowering the cost of wasted time due to congestion by 16 percent by 2030 and nearly 60 percent by 2050.

2.3.1.2. ECONOMIC OPPORTUNITIES

- **Increased potential for economic growth.** Economic growth, as measured by GDP, would be generated by a mix of greater revenues from the new activities, which have been done because of the circular method, and lower production costs due to more efficient input use.

  These changes have an impact on supply, demand, and pricing, as well as the GDP which according to a circular manufacturing development route, may grow by 11% by 2030 and 27% by 2050.

- **Substantial net material cost savings.** As stated by Ellen MacArthur Foundation, the yearly net material cost reduction opportunity in the EU is estimated to be worth up to USD 630 billion in the advanced scenario and 380 billion in the transition scenario involving a 19-23% reduction in inputs costs.

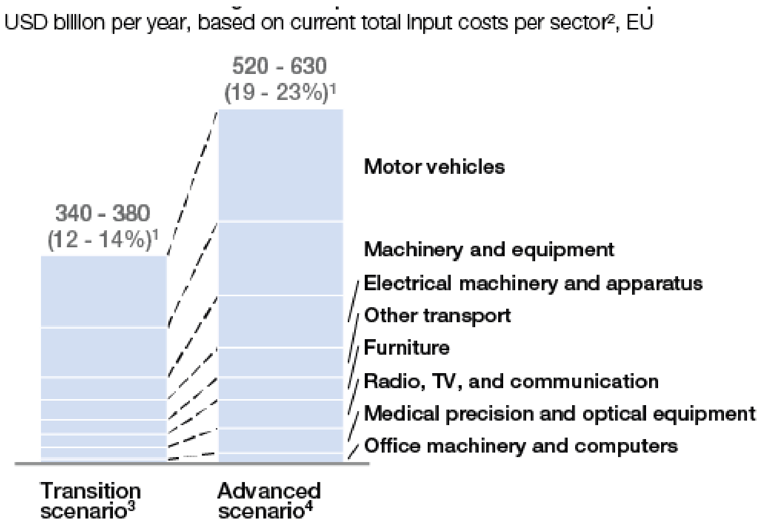


Illustration 9 Net material cost savings [10]

- **Job creation potential.** A slew of studies back up the premise that the circular manufacturing may help create jobs. The number of jobs created differs between research, reflecting differences in modelling methodologies as well as country-specific employment market and national economy variables [11]. The International Labour Organization reckon the net creation of 18 million green jobs by 2030. In this value it takes into account the manufacture with 4 million jobs and 9 million to the construction sector and the renewables [12].

- **Innovation.** The desire to replace the old-fashioned model with items that are circular by design, as well as establish other methods and protocols to support the circular manufacturing, has an enormous potential for new ideas. Higher rates of technical advancement, increased materials or more profit prospects for businesses are some of the advantages of a more creative manufacturing.

2.3.1.3. BUSINESS OPPORTUNITIES

- **Profit opportunities.** Companies that adopt the model of circular manufacturing can save input costs and, in certain situations develop totally new benefits flows. As claimed by Ellen MacArthur Foundation, the use of the approaches of this model might signify enhancements like:
  - If the industry made phones easier to disassemble, enhanced the reverse cycle, and gave incentives to return phones, the remanufacturing cost of the telephones might be cut in half.
  - It would be possible to have benefits of USD 1,90 per hectolitre of beer if it is sold the brewer's discarded brans
- **Volatility reduction and safeguarded supplies.** The possibility of geopolitical crises or natural disasters makes it more and more necessary moving toward a circular model because is a key component to be able to reduce the quantity of raw materials utilized. Instead, businesses would utilize more recycled or even reusable inputs with a bigger percentage of labour expenses, reducing their reliance on raw material price volatility.
- **The demand for new services.** According to Ellen MacArthur Foundation, new services can be defined and identified by the decision-making of senior managers or by employees at all levels and departments. Examples of new services could be:
  - Remanufacturing of parts and components, as well as product refurbishment, provide specialized expertise.
  - Companies that enable the reintroduction of end-of-life items into the system, such as collection and reverse logistics.
  - Sales platforms and product remarketers that help items last longer or be used more effectively.
- **Improved customer interaction and loyalty.** Circular manufacturing provides clients with new and innovative methods to communicate with them. Consumers become users, and one-time transactions turn into long-term service partnerships. Customer personalization and retention, as well as superior service and customer happiness, are all part of rental or leasing arrangements.

2.3.1.4. SOCIAL OPPORTUNITIES

- **Higher disposable income.** This economic model can help to increase the disposable income of an average European family. By 2030, EU families' average discretionary income would have increased by €3,000, or 11%, compared to the present development path according to Ellen MacArthur Foundation article.
- **Increased choice.** The additional variety or quality that circular models give may boost the usefulness or benefit felt by customers. As manufacturers develop mechanisms that enable customizing of goods or services to better fit client wants, customer choice expands.
- **Reduced obsolescence.** Nowadays, most of the products have an obsolescence that you may need to repair or return. The long-lasting or reusable item will benefit the budgets and quality of life of the consumers. For the customer, avoiding early obsolescence will lower overall ownership costs and provide more convenience because it will reduce the time of the repair and return.

2.3.2. BARRIERS

Aa previously said, the circular manufacturing provides several advantages and potential for the economy, business, society and for helping the environment. But why, if it has so much potential, do companies not apply this new production model? There are some barriers in this new method that do not allow an easy transition that stand in the way of its implementation and advancement.

The main barriers are illustrated in the next table. [13]

Financial	Cultural	Technological	Structural
Initial Investments.	Company culture of capital conservatism.	Quality compromising when constructing for Circular manufacturing.	In a decentralized business, the implementation of a new strategy. (CM)
Inventory.	Measuring success and achieving organizational objectives.	Disassembling the items is difficult, time-consuming, and costly.	Environmental considerations are given little weight in R&D undertakings.
Low virgin material price.	Lacking consumer awareness and interest.	Material that has been recycled or reused is subjected to quality control.	
Quantify benefits.			
Secure financial flow-related to refurbishing.			

Table 2 Barriers of Circular Manufacturing

2.3.2.1. FINANCIAL BARRIERS

According to research conducted by [13], the financial part has five obvious barriers that not allow an easy transition. The first one is the initial investments to restructure the industry for refurbishment, as well as the logistical flow for return and reuse. Because disassembling a tool takes far longer than assembling it, the cost that is spent must be included back into the cost of the products that will have been sold, and that calculation must be accepted. The companies do not have the entire machinery, and normally the volume is too huge.

Another barrier to consider is the inventory, due to investor concern as to whether the company does not work great. If that happens, the investors will look at working capital, because they want their investment back. Likewise, when companies do not go as well as expected, the products will remain more time in the inventory so it puts a lot of pressure via talks with the potential investors of your company and also the CEO with the number of items in the inventory. Normally companies want to reduce always the inventory as much as it is possible because you will reduce costs such as handling or safety stocks and the problem comes from the fact that in circular manufacturing a lot of inventory is needed. All this is already a conflict, therefore that needs to be reconciled.

On the other hand, an important aspect is the price of the virgin material that is exceedingly cheaper than the products it is used in circular manufacturing, therefore it is complicated to compete with them because the first reason why consumer choose a product is the price of it.

The last two barriers are less important with which a brief explanation will be made. The quantify benefits which the problem are the hard values such as payback or pure money that are difficult to quantify. And the other one is the secure financial flow related to refurbishing that is not a problem in Europe because is possible to secure financial and products flows but as the research says, the majority of the companies will not be staying in Europe in the future.

2.3.2.2. CULTURAL BARRIERS

The most mentioned cultural barrier the company cultural of capital conservatism. Businesses are exceedingly careful with its capital, and it is especially wary of making long-term investments and locking up resources without taking into account the effectiveness and efficiency. One example of this could be the profit goals which implies that if a worker wants to do anything that isn't 100% sure to be repaid, they will face opposition.

The Measuring success and achieving organizational objectives is the second barrier mentioned. As the department of Civil Engineering of University of Minho [14], the ability to assess a building's circularity is critical to the circular manufacturing paradigm's further development and the realization of its potential advantages at the building level. To capture the primary components of circular manufacturing in buildings, such as lifetime of concerned materials, inputs/output), and building's end-of-life plan, a set of indicators is necessary. The indicators are designed to evaluate, improve, and disseminate the performance of this method and a help to measure the success and achieve the goals of the company.

Last but not least, the lacking consumer awareness and interest. The third major hurdle comes from the customers themselves, who are accustomed to the previously outlined paradigm of consuming and discarding. And it is that, as much as many of them consider sustainability, they must battle a way of behaviour that was previously considered "invalid": recycling and reusing things, paying for use rather than ownership, assuming that remanufactured products are of comparable quality to new ones..., [15] thus firms who are committed to producing long-lasting and reuse products cannot compete with those that simply make the products that people are used to. When it comes to businesses, the primary roadblock is that the circular manufacturing idea has not been integrated into their strategy, purpose, vision, goals, or key performance indicators (KPI), making implementation difficult.

2.3.2.3. TECHNOLOGICAL BARRIERS

From the technological point of view quality compromising when constructing for Circular manufacturing is one of this category barriers. If material selection is oriented on environmental factors rather than performance, performance will almost certainly suffer. Ergonomics may also suffer as a result of the weight. Nevertheless, if the items were leased rather than sold, it is probable that some criteria would be decreased, and that the products would be less durable, because ownership would remain inside the company, and the business would not 'lose face' with the consumer if something went wrong.

Nowadays, disassembling the items is difficult, time-consuming, and costly, being another of the reasons why companies do not make the change to a circular economy. The items are made out of a variety of materials that are bonded together. It’s highly difficult and time-consuming to separate the different materials of the product, which is one of the reasons why it is not economically viable to keep them alive because it is cheaper to produce a new product than replacing the components which takes more time.

The third and the last one, material that has been recycled or reused is subjected to quality control. This is a potential barrier because it is unclear what happened to the material, therefore has to be an exhaustive control because maybe that component does not work after the recycle process or another option is melt down and repurposed it, however these cases might be prohibitively expensive. When a new product is manufactured, it is also verified that the quality is correct, so it must go through numerous controls; however, with recycled items, you must determine which components may be reused and whether they will operate. Hence why, this aspect is a very important barrier that makes it difficult to make the change to this new production model because we do not have that part, so we would have to figure out how it would operate, how much it would cost, and so on.

2.3.2.4. STRUCTURAL BARRIERS

This barrier focuses on the lack of policies that facilitate the transition to a circular economy, both the policies within the company and its organization, as well as those imposed by the different governments of the country where the company works or where the suppliers are located.

First of all, a barrier appears for decentralized companies. If it were rebuilt the model that the company is using, massive changes would be required in every aspect of their organization, and various divisions have different styles of functioning, so it's unclear how those might be harmonized. It would be difficult to coordinate internal divisions since, if the company invests in 42 circular manufacturing loops, it may have an impact on long-term growth in another division, which may be dependent on a supplier, etc. As a result, doing things one step at a time is critical.

The other main structural barrier is that environmental considerations are given little weight in R&D undertakings. Nowadays companies do not have time in the projects to evaluate environmental issues or search for measures to improve circular manufacturing, and they would be pushed to the bottom of the priority list. The environmental issues are now low on the priority list, and they are only addressed ate the conclusion of a project when it is time for refinement, due to, economically speaking, improving environmental aspects does not affect their economic growth.

2.3.3. INDICATORS OF MEASURE

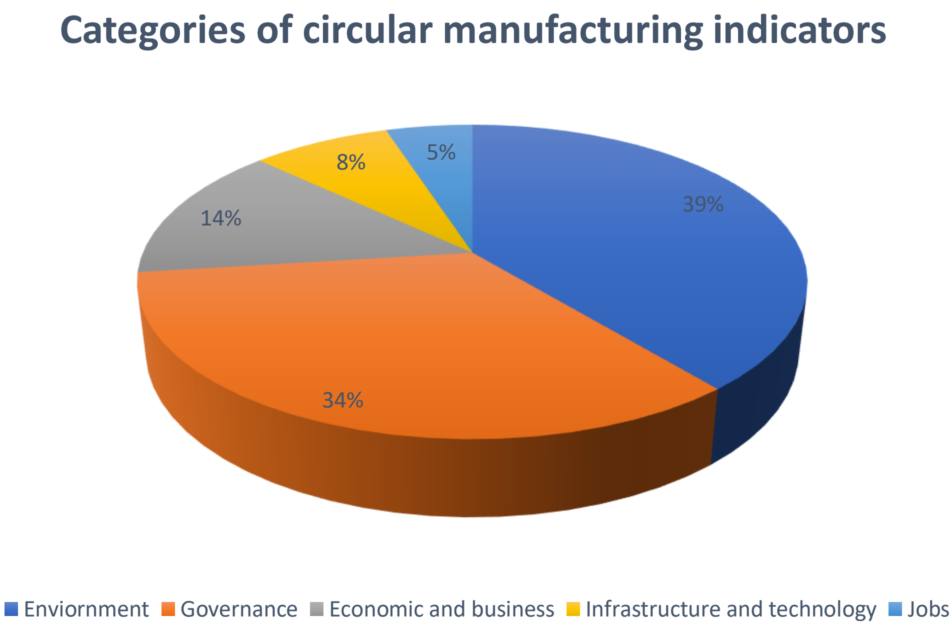
The performance of circular manufacturing must be measured using indicators in order to control the transition to a circular manufacturing and to quantify the effects of new policies and trends. Due to the enormous number of energy and material inputs and outputs in the circular model, these indicators are quite diverse, and can be evaluated as direct characteristics of the circular manufacturing or can be indirectly connected or influenced by this production model.

According to OECD [16], their inventory collects input, procedure and output indicators that are used by governments at various levels to track and evaluate all the progress of the implemented circular manufacturing strategies. The inventory gives an overview of measuring frameworks for the circular manufacturing, aids in the identification of measurement gaps and can serve as a model for governments intending to develop or use indicators to strengthen circular manufacturing policy.

This organisation divides circular manufacturing indicators into five categories:

- **Environment**: Focuses on indicators that have a direct influence on the ecosystem, such as output material process, toxic emissions, production, and consumption.
- **Governance**: Covers all the indicators that aim to educate, regulate and build the capacity, among others.
- **Economic and business**: Indicators represented in monetary terms, such as the value-added of the circular manufacturing and public investment the initiatives of this model, as well as metrics concentrating on activities carried out by and within enterprises, are included.
- **Infrastructure and technology**: Collect indicators with a direct impact of the measurement of the availability of circular manufacturing-friendly tools, technologies, and venues.
- **Jobs**: Indicators related to the issue of workers such as human resources or unemployment.

In the next graphic, shows the different percentages of the five categories of circular manufacturing indicators as maintained by OECD in their report. [17] It must be emphasized that the data obtained from the OECD referring to 474 indicators belonging to the five categories.



Graph 2 Percentage of the various categories

In terms of scale, the literature mentions three basic scales where measurements are taken: Micro (for example, a product or a business), Meso (for example, eco-industrial parks and industrial symbiosis), and Macro (for example, a city, province, region or nation) levels are all important.

A specified by [18], Firstly, the **Micro level** indicators provide precise information on single companies or local decision-making processes, as well as specific chemicals or individual commodities. They apply to a city, product, or company, and they surround policies and choices' execution in areas including product policies, energy efficiency, and integrated waste management.

Second of all, the **Meso level** indicators provide more specialized knowledge monitoring and a more detailed examination of material flows throughout the economy, distinguishing not only material categories, but also production sectors or divisions and consumption categories. They are relevant to an area, a product group, or an industry, and they encompass industrial and consumer activities to uncover waste of resources, pollution causes, and potential for efficiency profits.

Ultimately, the **Macro level** applicated in areas such as the economy, trade, and environmental policy integration, sustainable development strategies and action plans, and national waste management and resource conservation policies. The macro level, which is usually relevant to countries and broad regions, focuses on material exchanges between the economy and the environment, international commerce, and material accumulations in national economies, rather than on economic flows.

However, how can we measure all of these indicators? Aside from quantitative estimate of the indicator value, there are a variety of possibilities for relating this value to. Not all of them apply to all indicators. The value of the indicator can be linked to:

- Economic production, such as GDP and value-added, provides data on the economy's productivity and intensity.
- Per capita: to refer to a single person rather than an entire region or country.
- Input indicators: these are the materials that are mobilized to keep economic activity going. They depict the economy's material supply, whether taken from the domestic environment or imported, as well as underutilized flows.
- Output indicators: these measure the material outflows connected with a country's development and consumption. They maintain track of the items that have been utilized in the economy and are currently departing as pollution, trash, or exports.
- Consumption indicators: they show how materials used in economic activities change over time. The distinction between input and consumption indicators is significant.

3. LEAN MANUFACTURING

3.1. ORIGIN

As claimed by [19], Henry Ford was born in the year 1913. To construct what he dubbed chain manufacturing, he began by combining replaceable parts with conventional work and moving conveyance.

Ford used sophisticated machinery and lead/slow gauges to produce and assemble the components that would go into the car in a matter of minutes, and sent the flawlessly matched components directly to the line.

The issue with Ford's system was not one of flow: it could rotate company-wide stockpiles every few days. It was more his failure to provide diversity. The Model T came in a variety of colours. It was also confined to one standard, therefore until the end of manufacture in 1926, all Model T chassis were practically similar. (A feature from outside suppliers introduced at the end of the production line allowed the purchaser to choose between four or five body types).

Ford seemed to lose its way as the market demanded variety, considering model cycles shorter than the Model T's 19 years. Other automakers reacted to the need for a large number of models, each with a variety of choices, but with production systems that regressed into process areas with considerably longer lead times. They loaded their fabrication operations with ever-larger machinery that ran at ever-faster speeds, presumably cutting costs per process step while increasing production times and inventories, except in the rare case where all process steps could be connected and automated, such as in motor machining lines. Worse, backlogs between process stages and complicated part routings necessitated the development of more sophisticated information management systems, which culminated in computerized material requirements planning (MRP) systems.

That is where the Japanese company Toyota appeared having the roots of Lean. As explained in the article [20], the Toyota Production System may be traced back to the turn of the twentieth century. Sakichi Toyoda, his sons Kiichiro and Eiji Toyoda, and Taiichi Ohno, a production engineer, were the system's founders. Sakichi Toyoda, who worked in the textile business at the time, designed a motor-driven loom with a specific mechanism that allows it to stop if the thread breaks. The mechanism eventually served as a foundation for Jidoka (human-assisted automation), one of the two fundamental pillars of the Toyota Production System. Defects resulting from human-related flaws were decreased, and manufacturing capacity was increased, thanks to the use of a fault detection sensor.

Illustration 10 Logo Toyoda 1935

In contrast to the American car industry, Toyota encouraged employees to participate in the manufacturing process. Quality circles, a group of workers that convene to discuss workplace development, were developed by the corporation. Members of the quality circle provide presentations to management about production quality.

Toyota created a series of methods that cut setup and switch time in half. Toyota, unlike Ford, developed manufacturing in smaller quantities, which entailed a set of methods that lowered setup and changeover times [21]. It was not until 1990, when James Womack, Daniel T. Jones and Daniel Roos detailed the term Lean Manufacturing in the book 'The Machine that Changed the World'. In their 1996 book, 'Lean Thinking: Banish Waste and Create Wealth in Your Corporation,' Womack and Jones expanded this further, laying out five fundamental ideas [22].

3.2. DEFINITION

According to [22], Lean Manufacturing is a management and work organization strategy based on TPS (Toyota's production system) that aims to improve the performance of the companies, especially the profitability and efficiency of its output.

Lean Manufacturing improves processes by minimizing time spent on non-value-added tasks which in total are 8 wastes: 7 originally detailed by TPS and one that has been highlighted by many lean practitioners, as well as quality issues and complexities. This strategy is backed up by significant managerial component that ensures staff are working in the best possible conditions. In the end, there are two major goals: Complete each employee's achievement and client satisfaction.

Processes, activities, goods, or services that demand cash, time, or expertise but do not add value to the client are examples of waste. Underutilized talent, surplus inventory, and inefficient or wasteful processes and procedures are examples of these.

Eliminating these inefficiencies should simplify services, decrease prices, and give savings for a particular services or product to the client through the supply chain.

3.2.1. THE EIGHT WASTES

One of the most significant criteria for establishing a successful business is the elimination of needless operations. This notion is an important aspect of lean thinking and may help you boost your profits.

As previously mentioned, the TPS gave birth to the concept of waste elimination, with Taiichi Ohno describing the three primary roadblocks that might negatively impact a company's work operations, only focusing on the obstacle related to waste.

These obstacles are:

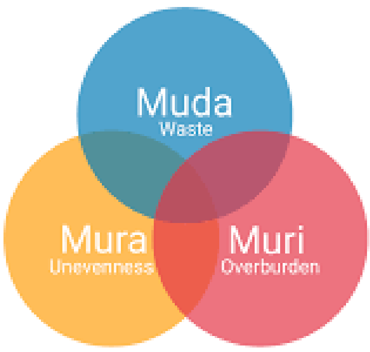


Illustration 11 The 3M of Lean Manufacturing

3.2.1.1. MURI

Overburdening or squandering as a result of attempting to achieve too much. This has to do with resource allocation and individuals being expected to undertake too much work. People may squander time switching jobs or even losing motivation as a result of being overworked.

3.2.1.2. MURA

Roughness or waste due to shifting demand, whether from consumer requests or an organization's addition of new services (and hence more work).

3.2.1.3. MUDA

It's any activity that uses resources but doesn't provide value to the end user. There are two types of waste in this category: those that are necessary even though they add no value, such as quality control of car parts, which is not an activity that the customer wants to pay for, but if you didn't, you could sell defective pieces; and those pure that are not necessary and add no value.

Following the explanation did before of what waste is in Lean, the 7 of TPS [23] + 1 practitioners wastes are examined in further depth.

Illustration 12 The 8 Wastes of Lean Manufacturing

- **Defects.** It might result in rework or, worse, garbage. In most cases, faulty work would have to be returned to production, which takes time. Additionally, an extra rework space may be necessary in some circumstances, involving additional manpower and tools.
- **Overproduction.** It's easy to see why excessive output is Muda. Producing more signifies you've outstripped client demand, which means you'll have to pay a higher price. Whether it's because it demands additional transportation, additional space in the warehouse or a lengthier wait... You'll also have to remake more units if a glitch develops.
- **Waiting.** This is the waste that is most easily identified. Waiting is pointless as long as the items or tasks do not move. It's easy to identify since squandered time is the most evident symptom.

- **Transportation.** This sort of waste occurs when resources (materials) are moved without adding value to the product. Excessive material movement can be costly to your organization and might compromise quality.
- **Inventory.** Excess inventory is frequently the result of keeping it "just in case”. In such cases, companies are compelled to respond to an unexpected demand, protect themselves against production delays, and so on. This typically offers little value, fails to meet consumer expectations, and leads in needless spending.
- **Movement.** This type of waste includes intricate and unnecessary employee (or machinery) movements. To put it another way, do everything necessary to create a process that requires employees to do as little as possible to achieve their duties.
- **Extra processing.** This type of waste is generally represented in work that adds or provides more value than is required. For instance, when a company creates a higher quality wrapper around its product, it is worthless because it will be thrown away after use and the client will not be prepared to pay for it, as well as incurring a higher cost.

Finally, after explaining the first seven deficiencies of TPS, the eighth defect, which has been established through time owing to the usage of practitioners, has to be discussed.

- **Non-utilised talent.** You won't be able to get the most out of your staff if you don't exploit their strengths, but in conformity with [24] loss of one or more of the following components is linked to the eighth waste: rewards, recognition, justice, evaluation, motivation, objectives, self-esteem, knowledge, and resources.

Illustration 13 Components of talent waste

3.2.2. KEY BENEFITS

Waste in the workplace, whether caused by idle workers, inefficient processes, or underutilized resources, is a productivity drain, and lean manufacturing aims to eliminate it. The incentives for this vary depending on who you question, but they range from increasing income to providing benefits to customers. Regardless of the overriding motives, lean manufacturing has four significant advantages:

- **Eliminate Waste.** Waste, as mentioned before, is a negative factor for cost, timeliness, and resources. It adds no value to the services or products even add less value.
- **Improve Quality.** Quality improvement assists companies in being competitive and responding to changing consumer expectations and preferences. Creating procedures that correspond to these expectations and objectives allows you to stay ahead of the competition while simultaneously focusing on quality improvement.
- **Reducing Costs.** Storage expenses are incurred as a result of overproduction or having more resources than is required. These expenses can be cut by improving procedures and material management.
- **Reducing Time.** Inefficient working methods waste time and money, whereas more efficient techniques minimize lead times and allow for faster delivery of goods and services.

3.3. 5 PRINCIPALS OF LEAN

In conformity with [25], Lean thinking is based on the TPS and is a method of specifying value, aligning value-creating tasks in the appropriate structure, doing these activities without interruption anytime someone requests them, and performing them in a more effective manner. This affirmation leads us to the five lean thinking principles: Define Value, Map the Value Stream, Create Flow, Establish a Pull System, and Pursue Perfection are all terms used to describe the concept of value.

Illustration 14 Lean Principles

- **Define Value:** To appreciate the first principle of evaluating customer value, it is critical to first understand what value is. The willingness of a client to pay for something is referred to as value. It is vital to identify the customer's true or concealed needs. Customers may be unsure of what they want or unable to convey it. This is especially common when it comes to new things or technology. Many resources can help you determine and uncover what consumers value, such as interviews, surveys, demographic data, and site analytics. Using these qualitative and quantitative approaches, you may understand what consumers want, how they want the product or service given, and how much they can pay.
- **Map the Value Stream:** The second Lean concept is to identify and map the value stream. The goal of this stage is to identify all of the behaviours that contribute to the value of the client as a reference point. Waste is defined as any activity that does not add value to the end user. The two categories of waste are non-valued added but important waste and non-value & unnecessary trash. The latter is pure waste that should be eliminated, whereas the former should be reduced to the maximum degree possible. By limiting and deleting unneeded procedures or steps, you may ensure that clients get exactly what they want while cutting the cost of providing that product or service.
- **Create Flow:** After the wastes have been eliminated from the value stream, the next step is to ensure that the remaining steps run smoothly. Breaking down procedures, redesigning production stages, balancing burdens, developing cross-functional divisions, and teaching staff to be multi-skilled and adaptive are some methods for ensuring that value-added activities go smoothly.
- **Establish Pull:** One of the most inefficient components of any industrial process is inventory. The goal of a pull-based system is to keep inventory and work in progress (WIP) items to a minimum while ensuring that all resources and information are available to enable a seamless flow of work. In other words, a pull-based system offers Just-in-Moment distribution and manufacturing, which allows items to be made at the precise moment and amount necessary. Customers' needs are always at the forefront of pull-based systems. By following the value stream and moving backwards through the production chain, you can ensure that the things produced will be able to meet consumer expectations.
- **Pursue Perfection:** The first four waste prevention process pieces have been completed and explained before. The fifth step in the quest of perfection, on the other hand, is the most important of all. It instils Lean thinking and continual process improvement into the company's culture. Every worker should strive for perfection while delivering items based on client needs. The company should be a learning organization that is always seeking for new ways to improve.

The five Lean principles lay the groundwork for developing a productive and efficient business. Managers may utilize lean to find inefficiencies in their organizations and give better value to customers. The principles promote better work flow and the establishment of a culture of continuous improvement. By adhering to all five principles, a company may remain competitive, improve the value it provides to customers, reduce the cost of doing business, and increase profitability.

3.4. LEAN MANUFACTURING TECHNIQUES

So far, we've discussed what Lean is, how it came to be, the benefits it offers, and the five principles it adheres to. This section will look at the many techniques for adopting Lean in firms. But first, some context is required. When it comes to the numerous Lean methods, some refer to them as tools, while others refer to them as techniques.

Tool, according to Oxford Languages, it is *"a device or implement, especially one held in the hand, used to carry out a particular function"*. WordReference define it as *"an instrument for some purpose or work"*.

Technique, according to Oxford Languages, it is *"a way of carrying out a particular task, especially the execution or performance of an artistic work or a scientific procedure"*. WordReference define it as *"any method used to accomplish something"*.

After evaluating the two meanings, it was determined that the technique word is more suited for defining the activities that contribute in the implementation of Lean. Because they are procedures rather than goods, and it is a philosophy or science of production rather than a trade, is a more full and exact description. As a result, it is suggested that they be referred to as Lean techniques rather than Lean tools.

It's also worth mentioning that several of the ideas outlined below aren't exclusive to Lean management. These are methods that Lean feels are appropriate for organizations and encourages their use; nevertheless, they are not all ways designed specifically for Lean, as some are also associated with Quality Management.

In this part of the thesis, after doing a comprehensive literature analysis and reading several papers on the subject, I have decided to elaborate on the following Lean Manufacturing approaches, which I feel are the most significant. The techniques will be explained below, in accordance with [23].

3.4.1. 5 "S"

The 5S technique is a Lean method for improving workspaces that is also one of the pillars of Kaizen. It is divided into five steps that may be completed in any sequence to assist any team in managing their workspace for maximum process efficiency. The acronym 5S stands for:

Illustration 15 The 5 "S"

3.4.1.1. SEIRI

In English "Sort", make a distinction between the tools, supplies, and instructions that are necessary and those that aren't. Take everything out of the work area that isn't absolutely required.

3.4.1.2. SEITON

In English “Set in order”, sort and organize all of your tools, equipment, files, data, supplies, and resources to make them easily accessible. Labelling should be done for all storage locations, tools, and equipment.

3.4.1.3. SEISO

In English “Shine”, establish cleanliness standards. Clean up any debris, grease, or grime. Cleanliness creates a safe working environment and highlights possible concerns.

3.4.1.4. SEIKETSU

In English “Standardize”, motivate the team to undertake steps 1–3 on a regular basis as a standard routine to keep the workplace in good condition. Set schedules and expectations.

3.4.1.5. SHITSUKE

In English “Sustain”, develop organizational commitment to 5S as one of your organizational values so that it may become a habit for everyone.

5S is an excellent technique to keep your team disciplined and improve the quality of their work, as well as a great way to minimize the 7 Wastes of Lean.

3.4.2. A3 REPORT

The A3 report is a single-page document that summarizes the whole process's findings. It normally has seven stages, although various versions are possible.

This report is created by following seven steps:

1. Precedent, the issue must be described simply and succinctly. The most crucial aspect of A3 is to minimize the problem in a straightforward and practical manner.
2. Current situation, the issue is contained within a procedure. It's about identifying it using real-world data. Using schematics and diagrams helps to make things easier to grasp.
3. State/Objective, after you have a comprehensive understanding of the current situation, you must set goals. Keep in mind that you do not yet have a complete picture. You can return to this step after you've finished the preceding steps and reached the "effect confirmation" stage to add more information to the basic objectives.
4. Cause analysis, show the analysis and findings graphically. The 5 Whys, are helpful in completing this section.
5. Countermeasures, after you've figured out what's causing the problem, you may start giving solutions. You may now return to the original goal and add further information. Countermeasures must always result in a clear knowledge of how the primary aim will be met.
6. Action plan, A strategy for implementing the countermeasures is offered, which includes a list of the activities that will be taken.

7. Tracking and result, it is vital to monitor your progress and validate the efficacy of your countermeasures. You must act whether the consequences are positive or unfavourable. If the results do not meet your expectations, you will need to revise the plan, re-implement it, and keep track of it. If the enhancements have a positive impact, you must spread them throughout the organization and eventually make them a norm.

Illustration 16 A3 Report

The A3 report is a logical thought process that attempts to reduce people's subjectivity by posing as a quick and succinct report that any worker can comprehend while constantly concentrating on the process and results.

3.4.3. HEIJUNKA

Heijunka is a Lean strategy for reducing inequities in a manufacturing process and avoiding overload. This allows you to adapt rapidly to changes in demand and make the best use of your available capacity. By using this technique, you may stop producing work in batches and start processing orders depending on client demand. You'll be able to save money on inventory since you'll have fewer things in reserve waiting to be purchased when order volume is low. When demand grows, your process and team will be protected from overload since you'll be producing value based on your takt time, or average sales rate.

$$Takt\ time = \frac{Total\ available\ production\ time}{Average\ customer\ demand}$$

This technique has two ways to level the production.

3.4.3.1. LEVELING BY VOLUME

Customer demand for a product is forecasted for a given length of time and divided evenly throughout those days. The same amount of merchandise is generated every day.

3.4.3.2. LEVELING BY PRODUCT

It entails determining the daily product demand and adjusting batches to the daily product mix.

To perform this technique, the Heijunka box is used to carry out this approach. This is a system that visualizes orders for each product and levels a production sequence based on average demand to produce an ideal flow.

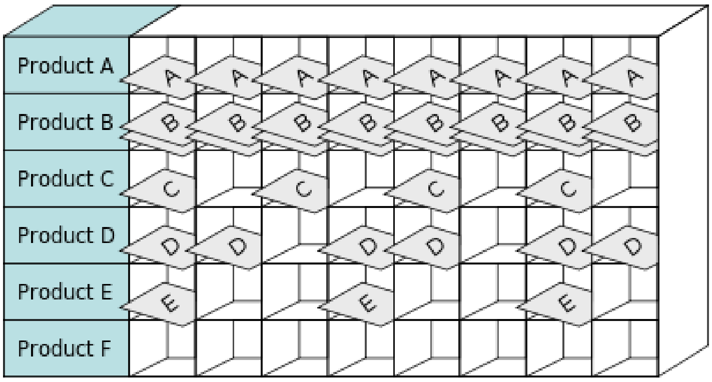


Illustration 17 Heijunka box

3.4.4. HOSHIN KANRI

As specified by [26], "The Japanese word Hoshin means "direction" or "compass needle." Kanri means "control" or "management." This reflects the intention of the technique to let the strategic goals of the organization guide every decision and action".

This is a critical Lean management approach for ensuring that a company's strategy is carried out throughout the hierarchy, and it is summarized in a 7-step process known as Hoshin planning.

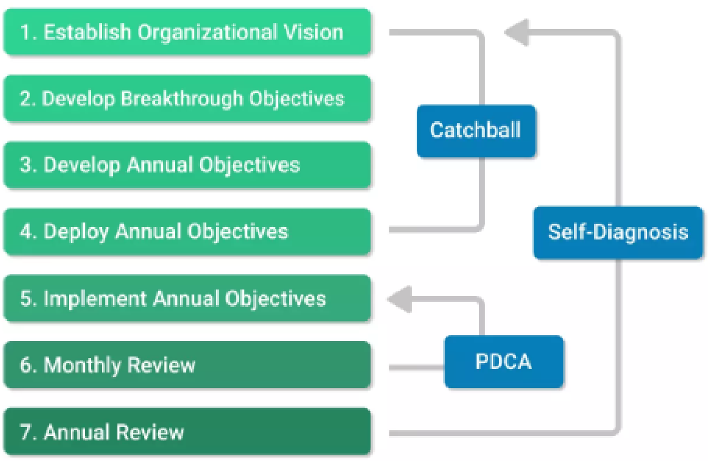


Illustration 18 Planification Hoshin

They are a collection of processes, forms, and guidelines that encourage workers to identify issues, make improvement plans, conduct efficiency checks, and take necessary measures, with the primary benefit being that all employees focus their efforts on the most essential areas of success.

Hoshin Kanri planning is not merely a top-down method, as seen in the image above. It has built-in continual improvement processes, which are critical to the method's success. These are the PDCA, consisting of 4 steps: plan, do, check and act; and Catchball tools, that is a method for creating and maintaining open feedback loops by establishing a two-way flow of information exchange at all levels of your organizational structure.

3.4.5. JIDOKA

The success of any organization's Lean implementation depends on establishing a continuous flow of activity. Instead of carrying a huge inventory, you will be able to give value to your clients just when they need it if you do it this way.

To get the most out of this technique of processing labour, you must ensure that the quality of your product meets the requirements of your clients.

To help you do this, Lean offers an approach called Jidoka, which is founded on four core steps. When an issue emerges, you will be able to interrupt your workflow and permanently resolve it by discovering the underlying reason.

This is a method is a popular Lean technique in manufacturing and product development. It's also known as automation, and it's a simple method for protecting your firm from giving low-quality or faulty things to customers while still attempting to keep your takt time under control.

It is composed by 4 simple principles to guarantee that the company is going to deliver the product without imperfections.

- Identify an anomaly
- Stop the procedure.
- Repair the problem immediately.
- Investigate and resolve the underlying cause

3.4.6. JIT (JUST IN TIME)

Not long ago, companies would overstock their warehouses with merchandise in case a customer requirement materialized, in order to ensure that possible demands that arise at the last minute would always be satisfied.

Having a massive inventory, on the other hand, obviously indicates increased expenses for keeping these additional resources. An Increase in inventories, by definition, necessitate more space and a higher number of employees for the handling of the products, that supposed which means an increase in the costs. To reduce the inventory costs, it was decided to apply a method called JIT (Just-in-time).

Just-in-Time originated as a basic inventory system in which manufactured objects or extra resources required for their manufacturing were only held when there was an actual need for products or services, rather than indefinitely.

This Lean strategy aims to cut production and waiting times as much as possible, limit failures, and keep inventory to a minimum in order to improve the company's efficiency and effectiveness.

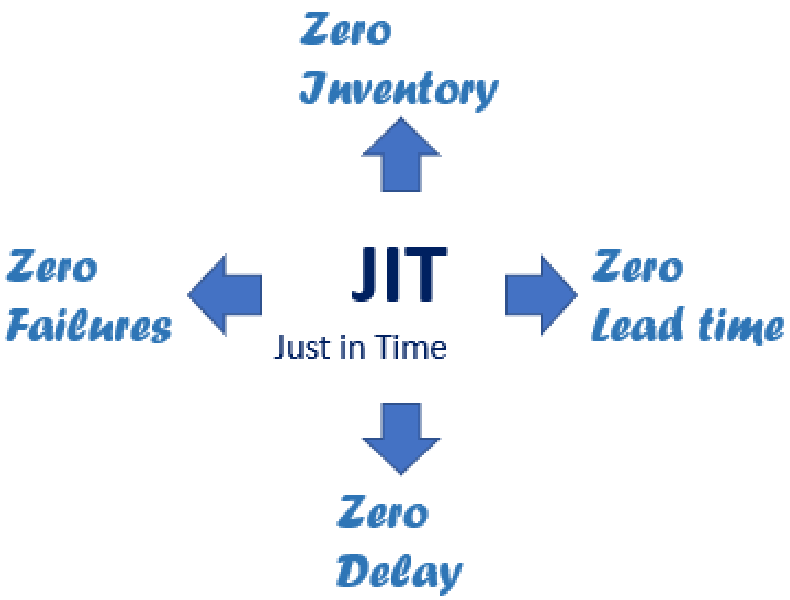


Illustration 19 Just in Time

Apart from assisting in the efficient use of resources, it also gives a number of benefits that will assist us in becoming more competent in the workplace. These are the benefits:

- Establishing a pull system.
- Eliminate waste.
- Visibility/Broad overview.
- Smooth workflow.
- Continuous improvement.
- Simplicity and flexibility.

3.4.7. KANBAN

Kanban is a method for assisting teams in establishing a balance between the work they must do and the time each team member has available. The Kanban technique is built on continuous improvement, with tasks "pulled" from a list of outstanding actions in a continuous workflow.

The approach focuses on completing the duties that have been assigned to you, and the most significant concepts are separated into four fundamental principles and six practices.

First of all, the 4 principles will be explained first:

1. Kanban does not require any configuration and may be used to identify issues in real-world processes or live operations. As a consequence, Kanban is straightforward to implement in any type of business because no big changes are necessary.
2. Due to the Kanban approach is designed to be adopted with minimum opposition, it deals with little, incremental, and evolutionary changes to the current process. In general, large changes are rarely considered since they are frequently met with opposition due to apprehension about the process or ambiguity.
3. Kanban believes that existing procedures, roles, duties, and titles have importance and should be preserved. The Kanban method does not prohibit, but neither does it stimulate, change. Because it is not scared to strangle progress, it encourages incremental development.
4. The actions of those who lead their teams on a daily basis give some of the best examples of leadership. Everyone on the team/department/company level must create a continuous improvement (Kaizen) mentality in order to attain peak performance. This cannot be accomplished at the management level.

David J. Anderson emphasized six fundamental concepts that must be followed in order for adoption to be effective. These six practices are:

- Workflow visualization.
- Remove any distractions.
- Manage the flow.
- Make Policies Explicit (Promote Visibility).
- Feedback loops.
- Collaboration can help you improve (using models and the scientific method).

In the next image there is an example of what is the method of Kanban and the organization that implies.

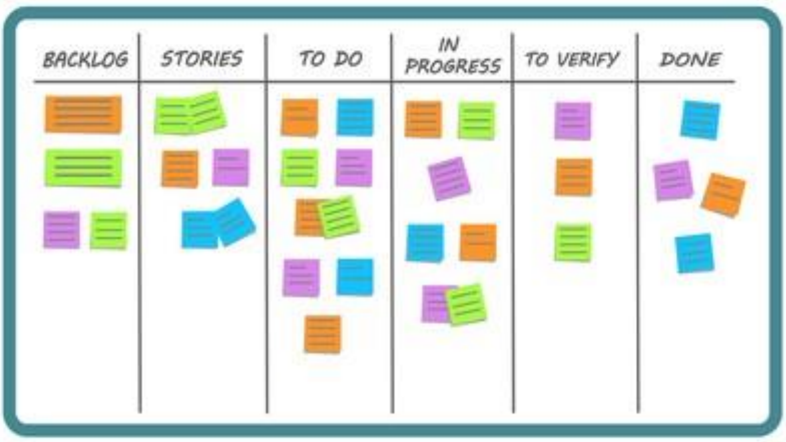


Illustration 20 Kanban control board

3.4.8. POKA-YOKE

Poka-Yoke (po-ka yo-ke) was a Japanese term established in the 1960s to ensure that the correct circumstances exist prior to conducting a process step, hence avoiding defects from occurring early on. When this is not possible, Poka-Yoke acts as a detective, finding and correcting process faults as quickly as possible. A Poka-Yoke is any mechanism in the Lean Manufacturing process that assists in the prevention of errors. Its purpose is to decrease product faults by preventing, correcting, or emphasizing human errors when they occur.

Poka-Yoke is a basic idea. Quality increases, rework is avoided, and time is saved when mistakes are avoided. This increases client satisfaction while cutting costs.

As claimed by [27], This method has two approaches:

- **Control Approach,** detects a fault and promptly pauses a line or process so that corrective action may be taken, avoiding the occurrence of serial defects.
- **Warning approach,** uses an increasing succession of buzzers, lights, or other warning systems to signal the presence of a deviation or pattern of deviations. The warning approach, unlike the control method, does not stop the process on every occurrence.

Three effective methods for detecting and preventing errors are included in Poka-Yoke devices: The contact Method, Fixed-Value and Motion-step technique; each method may be employed in either a Control or a Warning approach.

- **Contact method** identifies any alteration in shapes, dimensions, forms, position, or other physical aspects by using mechanisms that are kept in direct contact with the part. The touch approach can be used in situations where fast repetition, infrequent production, or environmental concerns such as inadequate lighting, critical temperature, dust, noise, and so on are present.
- **Fixed value** es applied, when the same actions are done numerous times. To control the number of movements, velocity, and length of motions, as well as other essential operational characteristics, the approach uses automated counters or optical instruments.
- **Motion step method** is useful for procedures that need several actions to be performed in a sequential order by a single operator. The procedure ensures that the operator does not accidentally do a step that is not part of the standard procedure.

Illustration 21 Example of Poka-Yoke

3.4.9. VALUE STREAM MAPPING

The VSM (Value Stream Mapping) is a highly strong approach for determining the worth flow chain. The value chain is made up of all the steps involved in transforming raw materials into finished products that are supplied to customers, as well as designing the flow from concept to launch.

In the examination of management processes in any company, it is a key managerial method. The goal is to identify those actions that might give the organization a competitive edge. The key benefit is that it provides for a holistic view of the processes, as well as identifying areas for improvement and prioritizing specific activities.

An example of the VMS is shown in the next picture.

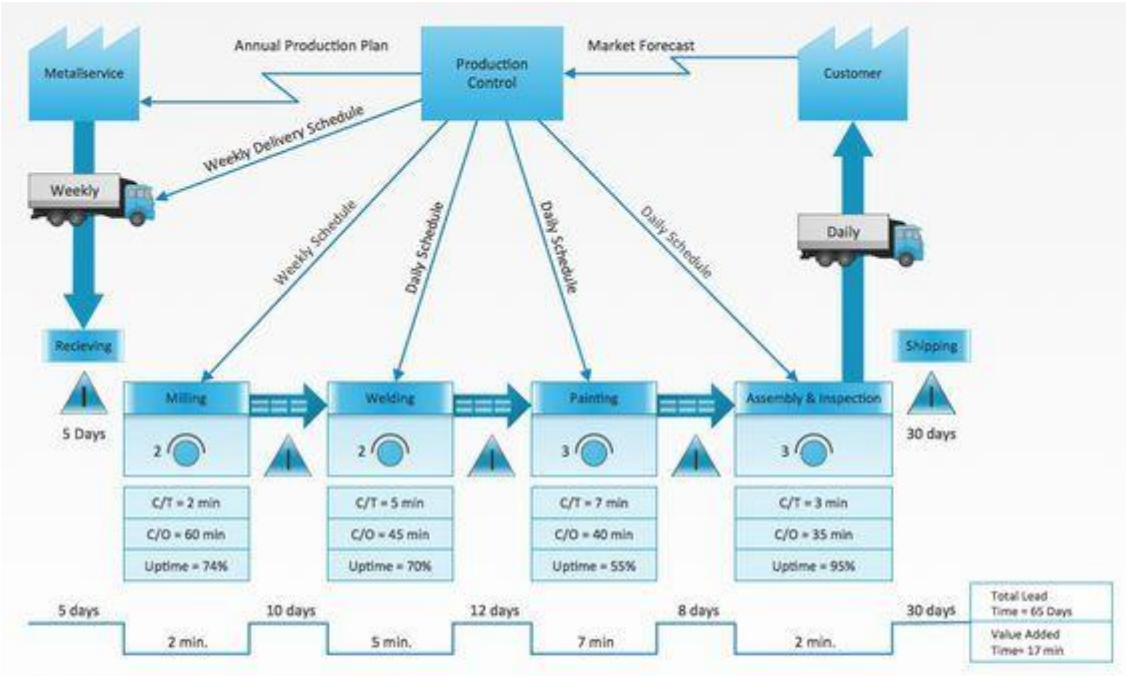


Illustration 22 Example of Value Stream Mapping

The following are the actions to take in order to get information about the process:

- Define the clause.
- Analysis of the process in the upstream. Following that, the activity times.
- Select the region and define the boundaries, making it clear what is and is not acceptable.
- Think about the movement of materials as well as the information required for that flow.
- Each process will have its own process box, which will display various statistics such as cycle time, added value, waiting duration, and so on.
- A triangle symbol is used to denote the inventory of each procedure.
- If the information flow is manual, it is represented by straight lines. If the information is electronic, it is indicated with a lightning bolt.
- Finally, a timeline is depicted underneath the processes, with times specified.

4. CIRCULAR VS LEAN MANUFACTRUING

4.1. WHY THE COMPARISON

This chapter examines the points of convergence and contrasts between the lean philosophy and the circular manufacturing, beginning with its conception and progressing through various features such as waste removal.

In today's world of manufacturing, lean manufacturing is the dominating production approach. Several lean manufacturing methodologies have been discovered to optimize productivity by removing waste and focusing on the benefit of the client.

However, as the importance of sustainable development has grown in recent decades, as mentioned in the introduction to circular manufacturing, issues have arisen concerning if lean philosophy not only adds benefits for the client, but also environmental advantages. As a result of this new focus, an academic debate has developed, attempting to determine if "lean" and "circular" have any synergies or conflicts. Much of this thesis is the comparison of the both methods, taking into account the similarities that sustainability and lean may be seamlessly linked to assure waste reduction for higher competitiveness, better resource use, and improved environmental performance. Moreover, the differences that they can have, since sometimes, although lean and circular go hand in hand, occasionally happens that lean methods and environmental concerns clash.

In order to supplement the present topic of the literature on the both methods, it has already been explained on the circular manufacturing idea, which has increased the popularity over the previous decade. The circular economy separates itself from linear "take-make-waste" production systems, having another alternative that the purpose is to “take, make and regenerate” by concentrating on the 7R's: reduce, reuse, recycle, redesign, repair, renovate, and recover throughout the life cycle of services and goods, resulting in reduced emissions and less resource consumption. Despite the fact that the notion has become well-known and has been adapted into a manufacturing setting utilizing the concept of circular manufacturing systems, only a few restricted research into its relevance to lean methodology have been conducted.

According to [28], it is believed that understanding the complementarities and contradictions between "lean" and "circularity" is essential. In contrast to lean, circular economy ideas such as 7 R’s, may progressively reach higher levels of organizations in a methodical manner, as opposed to lean's restricted internal operations. To broaden the perspective, they have been proposed three levels: system level, referring to waste/losses in the upstream and downstream of the distribution process before and after the manufacturing system, where waste/losses in lean and circular are perceived differently; process level, referring to the manufacturing process and whether it is lean and/or circular; and product level, referring to designing the product for lean and/or circularity.

By concentrating on these three different but interconnected stages, as well as their interdependencies, the economic and environmental benefits (and downsides) of circular procedures may be better defined and understood in contrast to lean manufacturing. Illustration depicts the three levels of the value chain of a company.

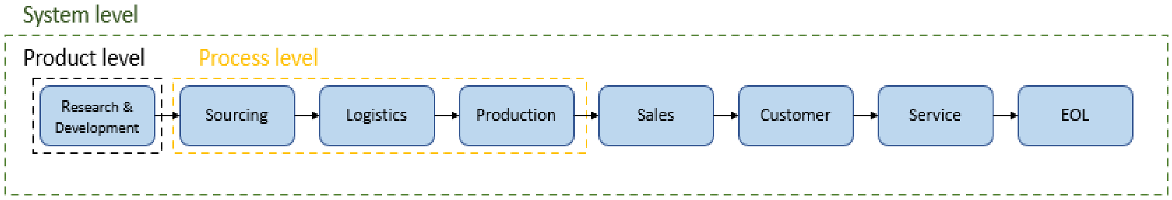


Illustration 23 Levels for comparison both methods

Nonetheless, the two manufacturing techniques will be contrasted, divided into four sections: overlaps, similarities, differences and contradictions, after a study of various research on the two production models. For this, all the identified comparisons will be considered, regardless of the degree of the three

At this point in the study, it should be noted that the terms "lean" and "circularity" are debatable. Lean may be viewed as a collection of methods, such as Kanban, Poka-Yoke, six sigma, and learning worker teams, that are implemented in a specific organization. Circular approaches are also diverse, spanning anything from recycling to material reduction. Because of the conceptual complexities, as well as the scarcity of papers that have directly addressed the relationship between "lean" and "circularity," our study aims to provide comparisons of both so that in the future it will be easier to implement the method known as "lean green," which is the fusion of circular and lean manufacturing.

Illustration 24 Lean Manufacturing vs Circular Manufacturing

4.2. OVERLAPS

After explaining the purpose for the comparison between these two organizational techniques in the introduction, we will begin with a discussion of the coincidences that have been explored between circular and lean manufacturing.

In the next picture, the figure below depicts two circles that correspond to the properties of the two techniques, crossing each other and demonstrating the many overlaps that the two have.

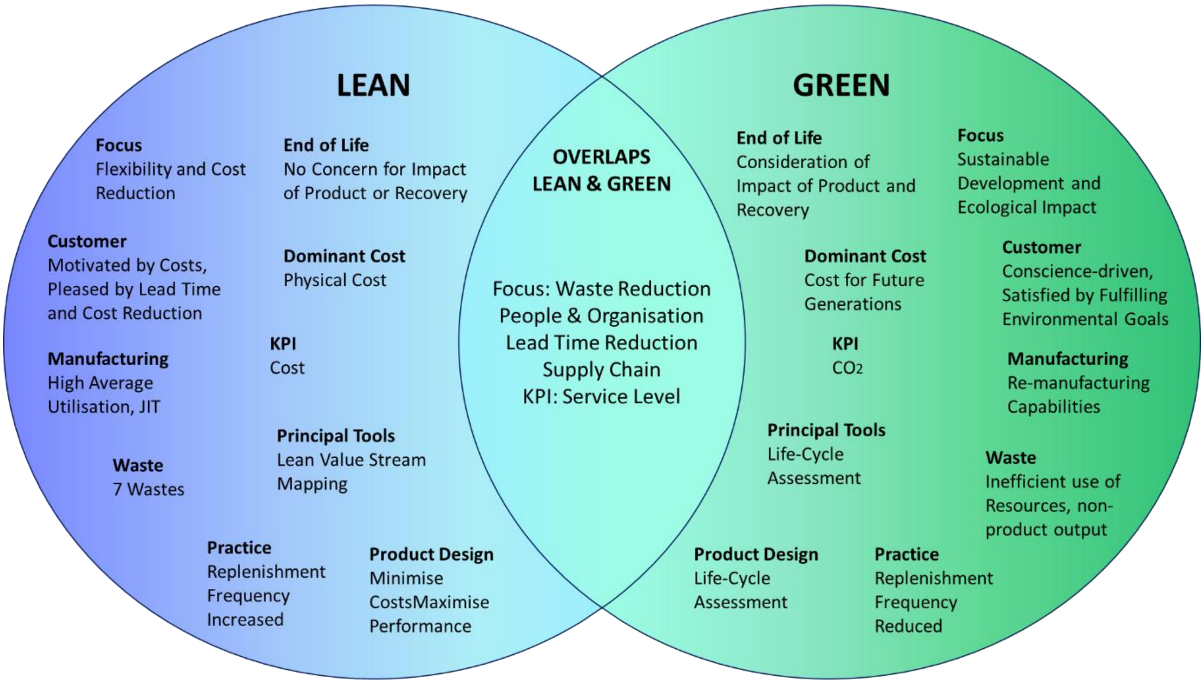


Illustration 25 Overlaps of both methods

These overlaps will be discussed in more detail in the next parts of the thesis

4.2.1. FOCUS: WASTE REDUCTION

The key point of convergence between the two philosophies is the goal of waste elimination. Although each model defines waste differently, in a very generic way, both aim to eliminate excess.

On the one hand, Lean considers all the 8 wastes of manufacturing, which have been explained before in the part of definition of Lean manufacturing, as non-value-adding activities. As a result, this strategy enables the removal of waste in order to decrease expenses as much as feasible while remaining adaptable.

Circular manufacturing, on the other hand, addresses environmental wastes such as wasteful resource usage or junk creation. This technique supports the resource efficiency, raw material consumption reduction, and garbage utilization, either through recycling or repurposing to generate new items. As a consequence, it will be available to satisfy the sustainability development goals and the ecological impacts.

Regardless of their distinction in the definition of waste, non-value-added activities might be deemed waste of energy and natural resources. Therefore, it can be considered that both target on the same type of waste even though the two models have distinct waste minimization goal. This is the assessment that demonstrates that the two models have the same aim of stopping waste.

4.2.2. PEOPLE AND ORGANISATION

The degree of the organisation and the satisfaction of both strategies are significant. Having effective organization in the various departments within the company, as well as good communication between managers and workers, is critical for all of the predetermined goals to be realized. These objectives would have been presented while keeping in mind the primary goal of all businesses, which is to please the consumer.

A lean organization recognizes the importance of customer value, which is one of the two key points of this part, and focuses its primary activities on continuously growing it. The ultimate objective is to give "perfect" value to the consumer through a "perfect" zero-waste value generation process.

To accomplish this, lean thinking modifies traditional management by optimising techniques, assets, and vertical departments in order to optimize the flow of goods and services to consumers. It is vital, and this is the other main point of this section, the employee's involvement in order to achieve this.

Indeed, Liker [32] proposes that the entire "4P" Lean manufacturing model (composed of Environmental Philosophy, Process, People and Partners, and Problem Solving) be founded on first establishing a management environment and awareness, and then fostering leadership to support the development of individual competence and responsibility.

Therefore, as claimed by [33], it's a win-win situation if you keep your people interested while you progress toward lean production. They will feel appreciated and valued, and you will receive greater assistance in working toward your objectives that is to satisfy the client by reducing cost and lead times.

The similar thing happens with the Circular Manufacturing approach. This Philosophy, also tries to satisfy the customer, but in this case, by helping them to being green. To accomplish this, Employee participation in environmental management is also critical in green manufacturing, just like in Lean manufacturing.

Employees are primarily responsible for and contribute to environmental management. Through education and formation, it is hope to foster a new mindset that emphasizes the importance of environmental challenges. With this, and the best efforts of workers and managers may be a key source of environmental benefits.

To summarize, both techniques need the participation of workers (employee's involvement) in order to fulfil the goals and thereby ensure customer satisfaction.

4.2.3. LEAD TIME REDUCTION

The Lead Time, is a different component that must be considered within a logistics network since it is the time that elapses between the issuing of an order and the reception of the item. Following the reading of several papers, it is determined that there are three categories of Lead Time.

- **Logistic Lead Time** refers to the time it takes a business to distribute its final product after acquiring the raw materials needed for manufacture.
- **Manufacturing Lead Time** is the time period between the commencement of the production process and the completion of a unit or a batch of units of a specific product.
- **GAP Lead Time** is the projection time of customer demands, that is, the span of time in which projections of future order amounts are established. The size of the GAP is roughly related to the inaccuracies made in forecasting.

After explaining what lead time is and the many sorts that exist within a company's logistics, it proceeds to show why the two approaches coincidence in reducing it.

In the case of Lean Manufacturing, the lead time of the entire manufacturing process is shortened, as much as possible without increasing costs, as a result of the appearance of numerous advantages. From delivering the order to the customer faster, which becomes a significant competitive advantage because it puts this company ahead of its competitors in terms of production, distribution, and delivery time; to the reduction of inventories, which occurs as a result of improved lead times and the elimination of the need for large quantities of items in stock; to the appearance of a sense of need for continuous improvement, since by having a reduced lead time, problems come to light sooner, therefore, the response capacity is greater.

Circular manufacturing, like lean manufacturing, calls for shorter lead times as long as CO_2 emissions are not increased. From the reduction of transportation lead time in order to minimize pollution to the reduction of lead time in the renewable circle process, as described above in the definition of circular manufacturing and illustrated in image 3.

4.2.4. SUPPLY CHAIN

According to [32], one of the characteristics of Lean manufacturing is to respect the expanded network of partners and suppliers by pushing them and assisting them with improvements. That is to say, tight collaboration with supply chain players is a fundamental component of the Lean approach. Likewise, good ties with consumers constitute a key for company success as the major goal of Lean is to generate value for the customers.

There is also a requirement for supply chain engagement in the green model. Environmental effects occur throughout the supply chain and therefore are not limited to a single organization. That is to say, all of the diverse players and activities in the supply chain have an influence on the environment. Environmental factors must consequently be included in supply chain considerations, and customer-supplier connections have a role in the environmental performance of commercial operations.

If a company shares and integrates environmental improvement ideas across different parts of the organisation, it will aid a manufacturing facility's ability to achieve high environmental performance, an increase in environmental awareness in manufacturing, or even direct engagement actions at the supplier level.

In conclusion, both Lean and Circular manufacturing emphasize the importance of supply chain actors in achieving company's success.

4.2.5. KPI: SERVICE LEVEL

The final point to mention in the coincidence section is the KPI, or key performance indicators. KPI, according to Oxford Languages, it is “*a quantifiable measure used to evaluate the success of an organization, employee, etc. in meeting objectives for performance”*. Investopedia define it as *“A set of quantifiable measurements used to gauge a company's overall long-term performance”*.

In this situation, the two philosophies share the primary Key performance indicator. This KPI is committed to providing the highest level of service possible. Both attempts to execute their different strategies in order to attain their respective objectives, but always achieving the service level that the customer is expecting.

Service level is a common and highly basic KPI that both models share, but if you go further into each, you will discover that they each have a separate KPI. This will explain in the difference section between both methods.

4.3. SIMILARITIES

This section discusses the similarities between these two production models. It varies from the preceding section (Overlaps) because the characteristics discovered are not completely same; they differ in numerous details, and so the difference is required in relation to the other qualities of the previous section.

The next figure depicts the different commonalities of these two methodologies in a more schematic manner, as was done before in the chapter on overlaps.

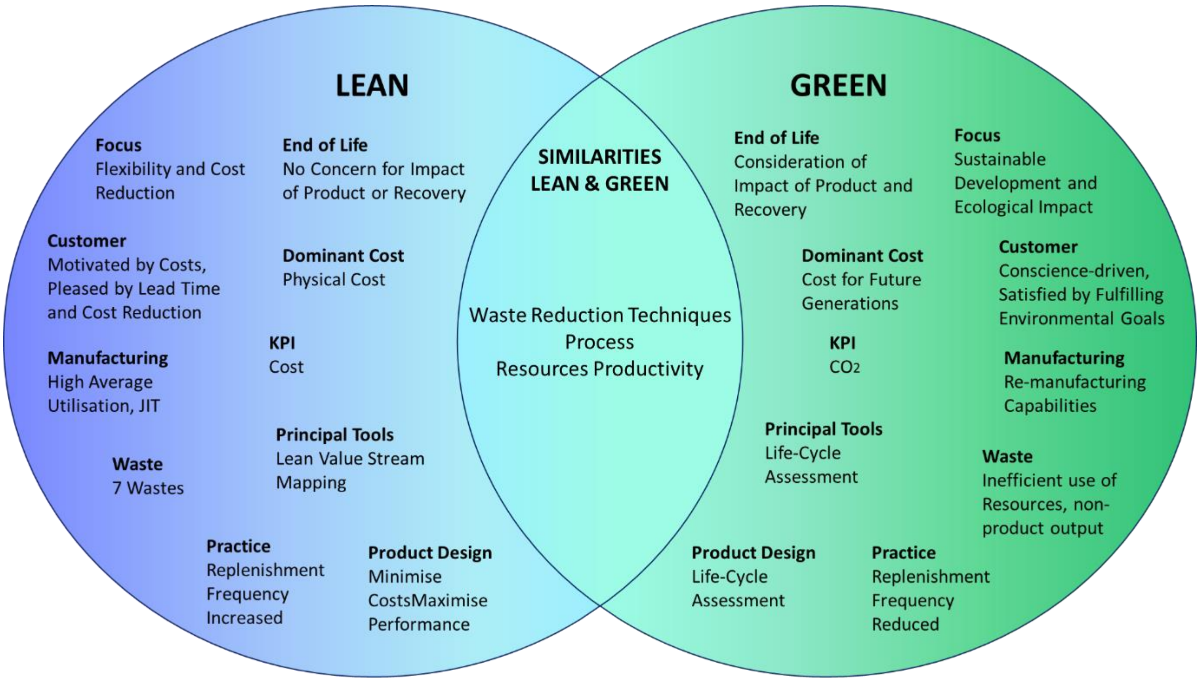


Illustration 26 Similarities of both methods

4.3.1. WASTE REDUCTION TECHNIQUES

All of the waste categories stated in the introduction to lean manufacturing may be found across the value chain, and lean production strives to remove them through its many methods. This is connected to circular manufacturing since purposefully and methodically removing waste consumes fewer resources for production and hence generates less waste.

Lean manufacturing employs a variety of methodologies and tools. More philosophical solutions, such as JIT, try to create flow, improve delivery precision, and eliminate overproduction on a larger scale. SMED, "*Single Minute Exchange of Die*", or Set-up time reduction is an example of low-level tools that aims to enhance available production time.

Regarding circular manufacturing, this method also employs a variety of techniques and technologies for the improvement of the production process of product quality. These techniques can be classed as assessment or improvement focused in general. Its goal is to evaluate a product's environmental impact throughout the course of its full life cycle (raw material extraction, material production, manufacturing, consumption and disposal). The evolution of various enhancing tools must also be considered.

As can be observed, there is a resemblance since the two methods employ distinct strategies to achieve the intended objectives, but it does not become an overlap because each tool has its own unique features and procedures, even though the goal is to minimize waste.

In summary, both Lean and Green manufacturing make use of various of approaches and technology.

4.3.2. PROCESS/PRODUCT

The major goal of the Lean concept is to improve industrial processes based on the philosophy of increasing productivity while reducing waste in a production environment. Nevertheless, even though this method is only focused on the process, it must be connected with the development of the product, because the design of the product determines the industrial conditions, which affects the performance of the system. This demonstrates a link between continuous improvement in the process and the products development.

As a result, even if we just focus on improving and making the process more efficient, we must also consider the product because our process improvements may differ based on the production to be carried out.

On the other hand, circular manufacturing addresses both factors. The fundamental purpose of this method, as indicated in previous chapters of the thesis, is to decrease and eliminate any waste that may contaminate or damage the environment. As a result, in order to be environmentally conscious, these principles must be used both during production and throughout product design.

In conclusion, while Lean manufacturing concentrates largely on the production process, it also recognizes the need of considering goods and product development. Instead, circular manufacturing requires a focus on both processes and products in order to produce industrial operations with low environmental effect. Therefore, both methods concentrate in the production process.

4.3.3. RESOURCES PRODUCTIVITY

The final commonality concerns resource productivity. Both techniques aim to maximize and utilize all resources in order to reduce waste. As claimed by [34], companies may improve their economics while increasing their value offerings to consumers and helping society as a whole by taking a holistic approach to resource productivity. Also, companies must work throughout the entire 'supply circle' to attain the maximum resource productivity potential.

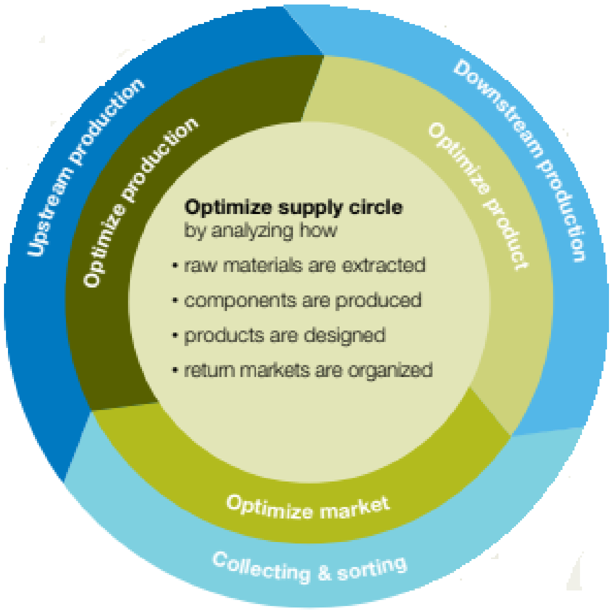


Illustration 27 Supply circle of resources productivity [34]

To optimize this resources productivity, companies should emphasize four major areas for resource productivity, depending on where they are on the production circle: production, product design, value recovery, and supply-circle management.

In terms of lean manufacturing, the concept's greater waste reduction in terms of inventory, rework, and so on, helps to resource productivity. Additionally, the circular idea advocates for less material waste and emissions, as well as fewer manufacturing stages that encourage high resource productivity.

Definitely, both models encourage a high resource of productivity, despite the fact that they have diverse strategies to enhance it.

4.4. DIFFERENCES

Many researchers concur that Lean and Green Manufacturing are complementary techniques that have a favourable impact on one another. It has been demonstrated that the two production models, lean and circular, share similarities and overlaps.

These two approaches, however, differ in several elements, such as the method's purpose or the client it is directed at, to the point of contradicting each other, such as the environment. With this, plus the fact that there haven't been many research on the fusion of lean and circular manufacturing, it's challenging to use both methodologies at the same time.

For these reasons, a study of the contrasts and conflicts between the two work philosophies is being conducted in order to better understand the connection and propose solutions for implementing the well-known "lean green" strategy.

4.4.1. FOCUS

The first distinction that can be identified is the focus of each model. Even though both tend to reduce waste in a general way, each one has their respective focus.

A drag system controls the lean manufacturing system, which is based on client demand. When a demand is received, an order is given using Kanban cards for the flow of resources and manufacturing for transformation.

Since mass production processes do not anticipate demand (push), finished goods do not need to be kept in stock for a long period.

As a result, waste will not be produced if they become obsolete or deteriorate while waiting for the essential demand to be developed. If this occurs, the items will have to be remanufactured, which will result in the waste of materials that cannot be recovered as well as the use of additional resources required to recreate them.

Pull mode manufacturing, on the other hand, is done in small batches, allowing numerous product combinations to be created economically without resorting to economies of scale. The SMED system is used in lean manufacturing to reduce machine setup times, which has the advantage of not accumulating inventory of production in progress.

Another advantage of this kind of production is that vast amounts of the materials that will be used in the process are not required, reducing the waste that inventories might cause.

Even though lean manufacturing views its suppliers as partners in supply management, the delivery of supplies in small batches does not necessitate the use of more resources in administrative purchasing processes, because, while orders are placed more frequently, formal and very specific orders are only placed for long periods of time, but they are scheduled for daily or weekly deliveries.

Furthermore, Lean manufacturing aims to address problems quickly while also figuring out where they came from so that they may be fixed at the source. Finding the source helps you to fix the problem and avoid future problems.

In addition, if the completed items are defect-free, waste due to poor quality is reduced, as these must also be remanufactured. There are several techniques and elements of lean production that aid in the elimination of such waste.

After explaining a recap of lean, although the lean philosophy is linked to the circular economy through the pursuit of waste elimination, the examined literature does not establish a clear link between the adoption of this philosophy and environmental sustainability.

Some writers demonstrate a direct relationship between the methods outlined, while others argue that there are trade-offs between lean production and environmental effect.

The fundamental difficulty in accurately defining these linkages is that there are no appropriate performance measures of the effects of lean manufacturing on environmental preservation.

In a nutshell, lean manufacturing prioritizes cost reduction and adaptability, while circular manufacturing focus in the sustainable development and the ecological impact. As a result, it is possible to argue that lean approaches are not strictly directed toward sustainable growth. However, these two models complement one other, resulting in not just reduced environmental impact but also improved operational performance. As a result, what is lean green and the benefits of combining the two ideas will be discussed later.

4.4.2. WHAT IS CONSIDERED WASTE

In accordance with [35], the most significant distinction between lean and green is how waste is described. As explained in the previous chapters of the thesis, Waste, according to lean, is defined as any action that does not offer value to the customer. Waste has been defined as any unnecessary step in a manufacturing process that does not give any benefit to the consumers and therefore is not worth paying for. The problem for circular manufacturing is the inefficient use of natural resources.

Despite the fact that both terms emphasize working to improve operational process, there exist some difference in other perspectives.

Lean focuses on staff reduction, space reduction, increased capacity utilisation, increased system flexibility, and the use of standard components [35]. This approach may be observed in the eight wastes of this production model, which were discussed previously in the introduction to lean: defects, overproduction, waiting, transportation, inventory, movement, extra processing and non-utilised talent.

On the other hand, circular manufacturing practices includes the 7R's: reduce, reuse, recycle, repair, renovate, recover and redesign. They are all a collection of acts that we may take as citizens to protect the environment and participate in the green manufacturing. The goal of this circular economy is to manage resources, recycle, and reuse to extend the usable life of all the things we use on a daily basis, so substituting the linear economy, which wastes resources continuously.

Although non-value-added activities might be regarded a waste of energy and natural resources in general, and so can be said to target the same waste, it has been established that each technique has its own viewpoint on what is deemed waste.

4.4.3. THE CUSTOMER

Although the primary goal of both techniques is to provide value to the client, this does not imply that they both target the same consumers because each production model seeks to please them in a different way. The Lean and Green frameworks are customized to a certain sort of consumer.

While the Lean consumer is driven and satisfied by cost savings and Lead time reduction, green consumers are motivated and satisfied when the products they buy enable them to be more ecologically friendly.

Nevertheless, the cost-conscious client will not object to the incorporation of circular manufacturing practices as long as doing so improves the cost-benefit balance. And also, green clients, on the other hand, are willing to pay less for their products as long as they are produced in accordance with environmentally sound principles.

Both production models target different customer although it could be possible to coalesce these two as long as it does not interfere with the principle driven consumers. This is another reason why it should apply the lean green.

4.4.4. KPI

A manufacturing KPI or metric is a well-defined and quantitative indicator used by the manufacturing industry to assess its performance over time. Manufacturing businesses, in particular, utilize KPIs to track, evaluate, and improve operations, frequently comparing their efficiency to that of rivals in the same industry.

We achieve better quality, lower costs, and faster delivery by combining the Key Performance Indicators (KPI) Lean Tool with the Customer Focus strategy. This was accomplished by using KPI Boards for issue solving to discover chances for improvement, determine the fundamental cause of the problem, and implement lasting solutions.

As mentioned in the chapter of overlaps, both philosophies share the same key performance indicator that is to give the best service level and the one which has been promised to the client. However, they have another different KPI.

In the case of lean manufacturing, the KPI to use is the cost and its reduction. The lesser the expenditures, as long as the grade of service is maintained, the better for both the company and the consumer.

On the other hand, circular manufacturing chooses CO_2 reduction as KPI to use. The more CO_2 that is eliminated, the better the environment will be, and so the approach will be used correctly.

4.4.5. END-OF-LIFE

In recent years, the circular manufacturing idea has been instrumental in detaching economic activity from non-renewable resource usage. However, non-renewable resources are becoming scarce, necessitating a more efficient usage and use of these resources. That is the reason why circular manufacturing can help to resolve this problem, being this method vital for extending a product life.

As claimed by [31], the term end-of-life is when a product no longer meets the requirements of the final user at the end of its useful life, it is referred to as a defective product. As a result, the last user of the product is referred to, and the product fails to satisfy the final user. However, many academics use the word in terms of the product's original user, which means that methods like reuse and modest repair are considered end-of-life strategies.

It is designated a Product Recovery Strategy (PRS), if the EoL option meets three primary criteria:

– Collecting all the used products.
– Reprocessing of a recovered product.
– Redistribution of the processed product.

The basic objective of circular manufacturing is to ensure that items that have reached the end of their useful life (EoL) remain in the economy for as long as possible by adding value to them. Either because it is recycled, because it is reused or because of many other options.

The picture below depicts the numerous stages that a product has had to go through in order to reach the end of its life. Beginning with design and production, which is handled by the manufacturer. Following that, it would be given to consumers with proper management and maintenance, for later, to be recycled or remanufactured and thus be able to use the same material or part of it again.

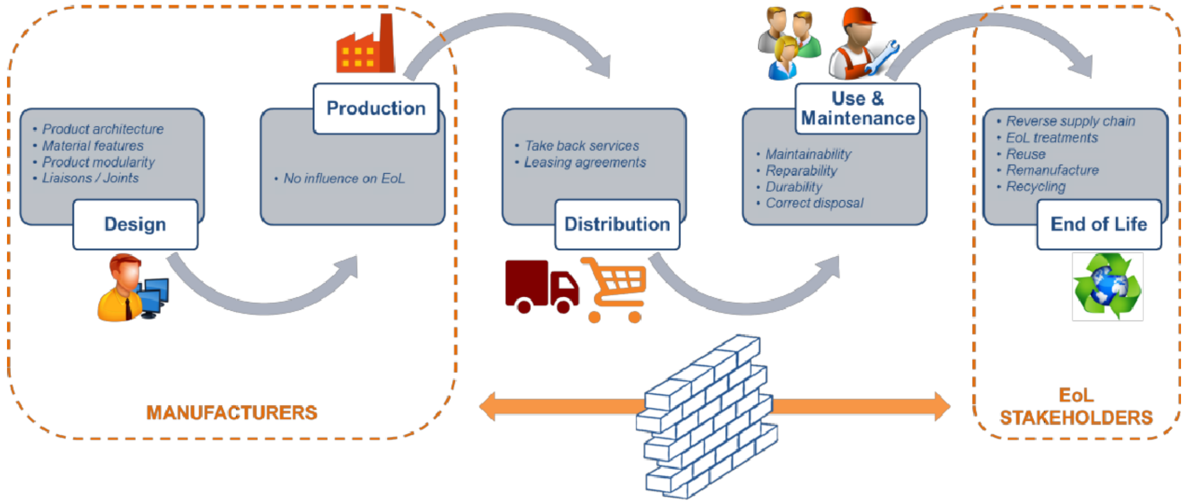


Illustration 28 The course of the product until end-of-life

In a nutshell, circular manufacturing is concerned with both the process and the finished product (design, materials, EoL...).

Instead, Lean manufacturing focuses on increasing competitiveness through adding value to customers, such as reducing the costs or having more flexibility, that is to say that this economic model focuses in the process.

However, although product development is connected to the process, because product design impacts manufacturing conditions and, therefore, the efficiency of the process, it does not focus on extending the useful life of the product. This is the reason why this method, unlike circular manufacturing, only focuses on the process and not in the end-of-life of the product.

4.5. CONTRADICTIONS

Following an explanation of the differences between the production models and the points of view which each has in various aspects such as the KPI, we will now proceed with the clarification of the contradictions that both models have and that make the simultaneous application of the two methods difficult.

It is divided into two sections: differences and contradictions. This is because having conflicts in concepts but being able to apply them together is not the same as contradicting each other, making it difficult to integrate the two models, such as the replenishment frequency, which requires an increase in lean and a decrease in green.

Despite the value of the synergistic link between Lean and circular practices, there are some circumstances where the two paradigms cannot coexist. These are the contradictions:

4.5.1. PRODUCT DESIGN AND MANUFACTURING STRATEGY

According to several studies, the only true distinction between Lean and Green is the differing perspectives both techniques have on the nature of the environment. Lean techniques regard the environment as a limitation for developing and manufacturing products and services, whereas Green approaches see it as a useful resource.

Lean manufacturing is a systematic manufacturing strategy for reducing waste in a manufacturing system. It considers the waste produced by unequal workloads and overload, and then eliminates it in order to enhance value while lowering expenses, that is to say, to minimize costs and lead time.

On the contrary, circular manufacturing promotes awareness of the environment, thus reducing pollution and making more use of resources without having a dependence on those that are not renewable.

The issue arises when some lean techniques do not promote environmental awareness, but instead increase pollution. The usage of the JIT approach is one technique that stand in conflict with the other production model because does not contribute with the environment.

As explained in chapter of "Lean Manufacturing Techniques", Just In Time is a method that helps organizations arrange their output. From purchasing through distribution, the strategy is predicated on eliminating anything that isn't required in the manufacturing process without taking into account the environment.

Therefore, in aspects such as the selection of the material, the batch production, or the transportation, using Lean methods to eliminate rework and operate on the premise of "get it right the first time" can stand in conflict with the green manufacturing principles [36].

- For instance, painting automobiles in batches of the same colour minimizes air pollution but is incompatible with JIT concepts.
- Regarding the use of materials, one example could be the automobiles manufacturers. When they use a spray paint for the cars, utilize ones that produce superior quality while also being more cost effective. On the other hand, spray paints cause more environmental damage.
- Lean advises a higher replenishment frequency by using a pull system with small batches and JIT delivery. This will result in an increase in transportation, which will not benefit the decrease of carbon emissions since the more the frequency of replenishment, the higher the pollution.

Clearly, not all Lean processes, procedures, and waste reduction efforts are linked to improved environmental performance or reduced pollution, and Lean approaches alone will never be enough to address all environmental challenges. That's the reason why it is explained later the lean green.

4.5.2. DOMINANT OF COST

Lean manufacturing concepts may minimize manufacturing costs by as much as half by boosting worker productivity, reducing production throughput times, reducing inventory, and minimizing mistakes and scrap.

Conversely, circular manufacturing places less emphasis on cost since its primary goal is to raise company workers awareness of the environment and encourage individuals to pollute as little as possible through minimising pollution. Since this is the goal, a number of costly procedures must be utilised in the process to achieve it. Furthermore, it is vital to consider the usage of materials that are not polluting, have a lengthy end-of-life, or are recyclable, all of which tend to be more expensive.

When discussing costs, it should be remembered that lean refers to physical costs, which are the prices associated to the value at the time of receipt or dispatch of the items, whereas circular refers to expenses for future generations.

That is the reason why these two strategies contradict one other, since while one strives to lower costs as much as possible while maintaining promised service levels, the other model requires an increase in costs in order to implement environmentally friendly practises, either by lowering carbon emissions or by limiting the usage of non-renewable resources.

That is why there is a discrepancy since one model requires spending to be able to implement it, whilst the other model requires it to be reduced. Although this makes merging the two models (lean-green) more challenging, when it would be discussed about the coalescing in the following chapter, it will be demonstrated that circular production processes may be used without significantly increasing the cost.

4.5.3. REPLENISHMENT FRECUENCY

As mentioned in the introduction of this thesis, 'Lean Thinking' is also utilized as a process for reforming businesses that consists of five phases that lead to Operational Excellence: Identify customers and define value, identify and map the value stream, create flow through the elimination of waste, recognize and respond to client need without interruptions and pursuing the perfection.

By focusing on time compression across the value stream, lean operations attempt to eliminate unproductive tasks. It is based on the idea that compressing time reveals quality problems that were initially unobservable and that solving them results in more efficient and profitable business operations.

Lean logistics approaches apply these concepts to whole supply chains. When a consumer "pulls" value by ordering a certain quantity of a product, that information is sent upstream via a supply chain of numerous organizations, and the amount that the customer has ordered of one product is delivered downstream in the shortest time feasible with the least amount of waste. That is the reason why Lean manufacturing requires a high replenishment frequency.

Lean logistics need an increase replenishment frequency of small quantity of items at every point in the supply chain, as well as the study of the flow of the items in time and distance. This is because, in order to prevent waste while simultaneously meeting client demand, they must be replenished several times in order to always have the exact demand. As a result, the client is pleased since they receive the goods in the desired amount and time, and no non-value added is produced.

On the contrary, circular manufacturing tries to do the opposite. Over the last few years, ethical companies have made significant efforts to cut carbon emissions. Some companies streamline their operations to increase energy efficiency, while others invest in greener technology to achieve low-carbon production.

As stated by [29], the choice to reduce emissions and the inventory policy have been the subject of recent studies. Several examples that they present in their study are: for the first time, Benjaafar et al. incorporated carbon emission concerns into a basic supply chain system and discovered that inventory optimization may significantly cut emissions without significantly raising costs, or Chen et al. developed a condition in which a change in replenishment amount may considerably reduce emissions without significantly raising costs, as well as an interval range in which the reduction in emissions exceeds the increase in costs.

In the next graphic you can observe how related are the increase of cost and the emissions reduction as calculated by [30].

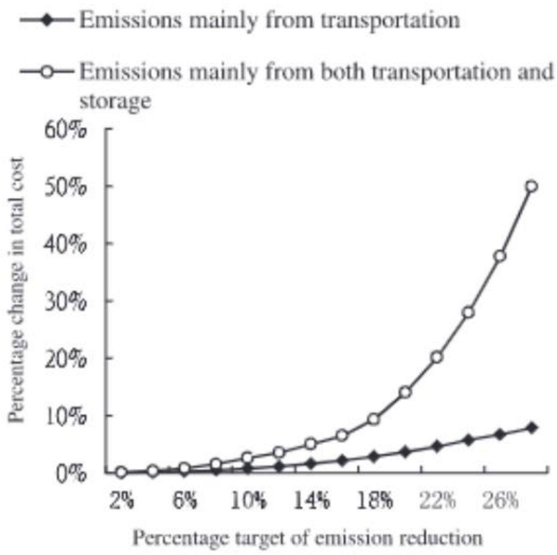


Illustration 29 Percentage change in total cost vs. Percentage target for carbon emission

This is why circular manufacturing prefers to lower replenishment frequency since it minimizes emissions, even if it means replanning your warehouse and increasing expenses, but after all, that is what is sought in this production model.

The existence of a discrepancy regarding the replenishment frequency is proven for all of the aforementioned. While one model seeks to reduce this in order to pollute less, the other requires an increase in replenishment frequency in order to minimize waste while satisfying customer demand.

5. LEAN GREEEN

Although there are numerous instruments to be able to produce effective production, it is essential to keep in mind that the most significant resource in the business is the human resources of businesses. It will be feasible to attain the targets in the best way if they manage the proper information and preserve the company's direction, which will include environmental goals set by consensus among everybody.

This is why a study comparing both production models have been conducted to see whether it is possible to combine the two processes into what is known as "lean-green."

According to [37], with the correct methods, Lean-Green (L&G) may provide a perfect foundation for generating cleaner, more value goods. This strategy tries to provide a plan for lowering waste treatment costs while also improving environmental and social consequences. Furthermore, as compared to the individual method, the L&G strategy complements and improves the efficiency and effectiveness of operational outcomes.

The combined lean-green strategy enhances environmental performance while also providing commercial benefits. Integration across departments, corporate culture, staff training and development, and customer interaction all play a role in the successful application of manufacturing systems like "Lean-Green." Indeed, top-down management commitment, as well as staff participation, are critical to the successful adoption of LG manufacturing inside a firm. Employees should be encouraged to grasp the economic and environmental elements of change, which is a crucial problem in the lean-green strategy.

Both techniques are compatible because of their synergy, positive relationship, and same aim seen in their benefits. Lean-green is an excellent strategy for a business to produce high-quality goods and services while also protecting the environment. Lean-green has several advantages, including lower costs and waste, better customer satisfaction, more production, and improved market position, product design, and reputation. The organisation reaps long-term benefits from using the lean-green strategy. Communication across departments, training, staff growth, and top management commitment are all important components in the successful execution of this strategy. In general, the human aspect is critical to a successful lean-green deployment.

6. CONCLUSION

The idea and principles of two production models, Lean and circular manufacturing, have been addressed in this study in order to compare them and identify the strengths and weaknesses of each in light of a prospective merger between the two.

Even while the phrase "circular manufacturing" literally corresponds to the re-circulation of resources back into the manufacturing process instead of a linear system, it impacts and is impacted by many other areas of the environment. For the circular manufacturing model to succeed, businesses and consumers must be brought together.

According to the literature, the notion is highly broad and complicated, which might lead to confusion and controversy. Nevertheless, rather than focusing just on the notion, it may be beneficial to consider its surroundings. All types of things are mass-produced in large quantities, thanks to trends like rapid fashion and the rush to provide new technologies as quickly as possible. Consumers are getting more demanding and eager to acquire new items without regard for the old ones they may have, but they are also becoming cleverer and more thoughtful, which implies that a product may now be judged on more than its appearance, specifications, or intended use.

Sustainability may become a new market criterion as a result of the opening of a new competitive category. In any case, customers do not have to go out of their way to learn about circular manufacturing; thus, it is up to manufacturers and service providers to supply them with guidance and information.

On the other hand, Lean strategy, it has been discovered, develops knowledge and transforms the production process and organisational culture in general. When Toyota Motor Company implemented what is now known as lean production, it created a good knowledge and caused a lot of changes to the existing system at the time: the main actors involved faced resistance to the transitions and new knowledge they had to learn, but they overcame it and created a successful system. This may be used as a model for combining the models in the future, but for a future integration, take the best practises from this experience and add some particular tools from complimentary models, as illustrated in this work.

Having made the comparison of both methods, reveals that, even if it seems not, these methods are mutually beneficial and with some similarities and overlaps. Both techniques improve material productivity and lead time reduction in production. By decreasing waste in inventory, labour, and other fields, the Lean strategy helps to boost resource productivity. Likewise, the green definition implies less waste production and pollution, as well as fewer production phases that allow for high material productivity. For both production models are needed the employee involvement and training to achieve the goals.

As a result of the comparison, the ideas are comparable in terms of resource efficiency, organisational transformation, and waste reduction.

Nevertheless, although there are similarities, various differences and contradictions can also be found. In essence, the concepts are focused differently, implying discrepancies and potential conflicts that must be controlled. For instance, to apply the techniques used in circular manufacturing to reduce effects on the environment, a large investment must be made and this completely contradicts the lean philosophy because it is perceived as an unnecessary expense that does not directly contribute to customer value.

The theoretical usefulness of the comparison offered in this work is that it serves as a springboard for additional investigation into the ideas' linkages, which is currently lacking in empirical research. Such research is critical if present manufacturing theory is to be extended to a more comprehensive view of resource productive production, thus in the future, to be able to coalesce both methods therefore the companies will apply what is call “lean-green”.

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