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Sustainability Key Performance Indicators for Mass Customization

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Abstract

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Today's manufacturers are striving towards a more sustainable and customized product offering in their value chain to satisfy customer demand and compete on the marketplace. By adopting sustainability practices, companies are not only complying with environmental regulations but are strategically addressing the triple bottom line (TBL) of sustainability (environmental, social, and economic). Similarly, mass customization allows a company to better satisfy their customers by creating individualized products economically. Moving forward, it is important to better understand the relationship of these two competitive strategies. In order to assess the sustainability performance of mass customization, it is important to understand the appropriate key performance indicators. The following two research questions emerged: 1) Can we define a generalized set of KPIs for the regular manufacturing industry? and 2) How are these KPIs related to manufacturers offering mass customization? The objective of the thesis is to develop a general model of sustainability KPIs for manufacturer's offering mass customization.

The research methodology included a systematic literature review of TBL KPIs resulting in a database of over 300 KPIs that were clustered around strategic goals. Following, the relationships of the KPIs in the mass customization and mass production industry were analyzed. To identify the KPIs of mass customization, the recent sustainability reports of three major companies (Nike, Dell, Danfoss) were analyzed. The comparison of identified KPIs from mass production and mass customizations and the findings indicate a mix of positive and negative impacts of mass customized product offerings on the TBL sustainability KPIs. A limitation of the analysis is the use of secondary data. The results can help traditional manufacturing companies to understand the opportunities of integrating sustainability and mass customization in their supply chain to create value for customers.

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1. Introduction

Sustainability is becoming a business imperative with the rise of conscious consumers [1]. The traditional concept of sustainability is believed to be conserving the planet and its natural resources. Sustainability used to be confined to the discussion of recycling materials and waste, use of renewable energies, reducing emissions, etc.[2][3]. However, the true application of sustainability is much broader and deeper for businesses. Companies are integrating sustainability in their product innovation and development as a business strategy that also protects the natural environment and human health [4]. Sustainability allows companies to create greater value for customers and their shareholders while respecting social and environmental resources [5]. The leading global brands are using sustainability to perform better in a competitive market [6]. Adopting sustainability principles, companies can create strategic differentiation to create long term profit [7]. For example, sustainability encourages to use reusable materials and renewable energy. The investment for recycling plastic becomes unnecessary which increases the profit margin of a product while complying with environmental regulations. At the same time, the companies can attract customers seeking "green" products, which eventually will result in building better brand loyalty. Thus, sustainability is believed to be a win-win strategy in the dimensions of profit, society, and the environment [8].

Companies are trying to achieve sustainability by offering eco-friendly products [9]. At the same time, customers are looking for a variety of products with different options to choose from. They want customized products made specifically for them [10]. Customization however tends to increase the production and thus product cost of the business, and reduces the opportunity to buy in bulk. From getting custom designed sneaker to a custom designed car, there are different kinds of personalization and each of them incur different cost. However, the companies can always charge more and earn a higher margin for a customized product/service. In a survey report from Deloitte, 1 in 5 customers are willing to pay 20% more or so for a customized or exclusive product [11] . In addition, customized products increase the customer satisfaction by increasing the value of the product. It leads to an increased feeling of customer brand loyalty. It creates more referral opportunity by increasing the word-of-mouth opportunities for the brand. By offering customized offerings, the brands are building a better customer experience and making their customer unique. Moreover, when the companies are letting their customers build the product, they are getting customers feedback from while making them. It can help any business to have a better product market in an ever-changing market [12].

To summarize, customers want eco-friendly products, and they want them to be individual items, ideally customized or even personalized for them. Therefore, the traditional value creation process of any product needs to adapt to this new reality. Companies need to integrate sustainability and mass customization in their value chain to be successful in the competitive business marketplace. As much as it sounds interesting, there is a standard solution to add mass customization in existing production lines. Questions such as what feature, size, or color should be offered as a customized option, or how much (of the product/service) to be customized still remain unanswered for most companies. Also, do their available resources (such as machinery, skilled employees) allow them to transition to customized product manufacturing? Is their supply chain flexible enough to give them room for customizations in their product?

Therefore, even though sustainability and mass customization are not new in the research fields, there are not enough studies of their applications in the business. However, the rising trend of Industry 4.0 and additive manufacturing technologies, are motivating companies to look at them from a different perspective now. Blockchain technology, artificial intelligence (AI), robotics and cognitive technologies, augmented and virtual reality can unify different processes in an organization to give them a better chance at achieving sustainability [13]. Companies are looking to develop and/or implement digital tools to measure their performance over the full product lifecycle, energy efficiency, pollutions, wastage etc. Application of the Internet of Things (IOT), Big data, sensors are used to collect data and monitor such metrics. All these innovations help companies to achieve better visibility and insights into their performance. As a result, IOT as an element of Industry 4.0 has an impact on sustainability development [14]. Also, the 3D printing technology is encouraging environmental-friendly productions by reducing raw materials, waste, and energy. In addition, 3D printing allows flexible and customer-driven manufacturing of small batch sizes (down to batch size 1) which eases the mass customization application too. Therefore, it is important to explore the opportunities of integrating mass customization and sustainability.

The objective of this thesis is to find a link between sustainability and mass customizations with respect to the triple bottom line dimensions - economic, environmental, and social. The Key Performance Indicators (KPIs) of mass customization can help organizations to better understand the difference compared to mass productions. Therefore, the thesis aims at developing a general model of sustainability KPIs for manufacturer's offering mass customization. In the process, a comparison between the KPIs of mass customization and mass production is investigated. The main research questions addressed in this thesis are:

- **RQ1:** What are the standardized set of KPIs on different mass manufacturing industries?
- **RQ2:** How those KPIs of the mass manufacturing are related to customized manufacturing industries?

Figure 1 presents a brief overview of how this thesis report will flow:

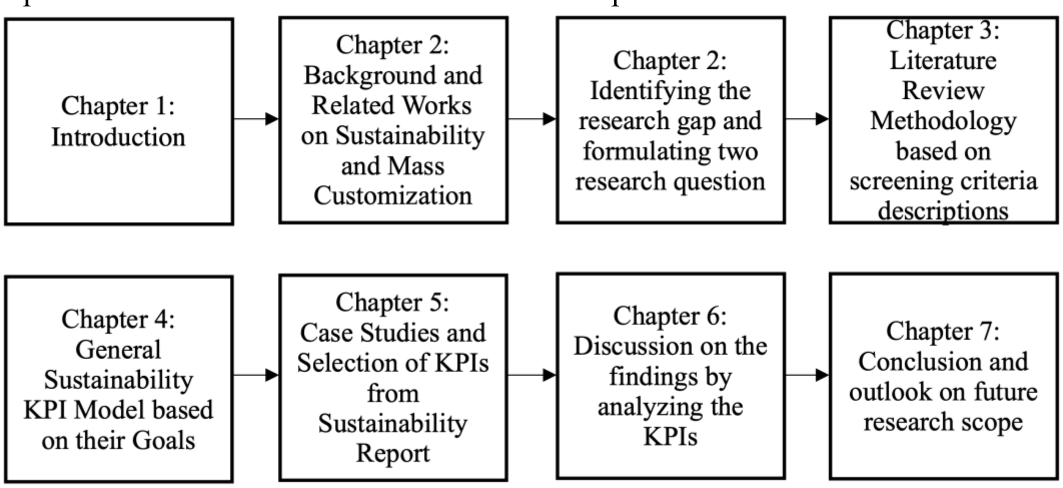

Figure 1 Overview of the Thesis Report

In the next section, backgrounds and related work of sustainability and mass customization are discussed to help with the following methodology of the thesis.

2. Background and Related Work

There are several studies conducted in the field of sustainability over the years. In this section of the thesis, different aspects of sustainability are described from several literature.

2.1 Sustainability

2.1.1 Definition

There are many definitions of sustainability that look into economic and social aspects of sustainability in addition to environmental. Most widely used definitions of sustainability come from Our common future (also known as the Brundtland report)[15]. In 1983, the former prime minister of Norway, Gro Harlem Brundtland was appointed the to run the World Commission on Environment and Development. Many countries tried to raise the living standards through industrialization, but they were still dealing with extreme poverty. It showed that the economic development sacrificing the social equity and environmental health did not bring meaningful prosperity. It means the world needed a way to harmonize ecology with prosperity. Then after four years of continuous development in the sustainable study, the "Brundtland Commission" released its final report, Our Common Future. It famously defines sustainable development as: "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." In another definition from the University of Alberta, the Academic Advisory Committee for the Office of Sustainability in 2010 defined as "Sustainability is the process of living within the limits of available physical, natural and social resources in ways that allow the living systems in which humans are embedded to thrive in perpetuity" [16].

2.1.2 Benefits of being a Sustainable Company

Companies can differentiate themselves from their competition when they consider the sustainability practices in their business practices. However, sustainability does not mean manufacturing environment-friendly products only. It has a long-term affect in their economic performance and their reputation among its stakeholders. Here are few key benefits of being a sustainable company:

1. Sustainability Saves Money: Adopting a sustainable business strategy by using energy-efficient resources and reusable packaging materials can save companies money. Using plastic materials in packaging is not only harmful for the environment but also very costly for recycling [17].
2. Sustainability Builds a Bigger Audience: Global warming awareness raising customers concern on choosing green products. Thus, reducing the companies carbon footprint can attract a lot more customers.
3. Sustainability Gives Tax Incentives: Adopting sustainability helps not only complying with government rules but several tax incentives. According to epa.gov, Federal, state, and local governments offer a range of financial incentives for undertaking environmentally responsible activities.
4. Sustainability Means Better Employee Retentions: Employees work better when they have a bigger cause to work for than just selling products. In November 2019, there are around 2300 employees from Google signed a letter calling google to commit to releasing a companywide climate plan that includes zero emissions by 2030, zero funding for climate

denying individuals/organizations, etc. [18]. According to a glass door survey, 75% of the employees who are aged between 18 to 34 take a stand on equal rights, climate change, etc. [19]

5. Sustainability Gives Extra Edge from Competition: In a 2011 survey of 4000 managers from 113 countries, 70% of companies have placed sustainability permanently on their management agendas [20]. Integrating sustainability in the company policy increases the brand image and generates high band value. To establish longer customer loyalty and profitability, companies are looking to produce high quality products respecting natural resources.

However, achieving sustainability is not an easy task. To be sustainable, a company needs to maintain different elements of sustainability which include the people, planet, profit as coined by Elkington in 1997 [21]. There are few other scholars who presented sustainability in different terms. Carroll, 1979; Friedman, 1970 looked into the corporate social responsibility of the businesses towards society [22][23]. Galloe and Christensen (2011) described sustainability as corporate agendas. The agendas include financial and extra financial goals including social responsibility, environmental protection, poverty alleviation and stakeholder commitment [24]. They emphasized how companies need to address the financial, social and environmental impact to strive for sustainability. Thus, sustainability is the interdependent relationship of financial, social and environmental dimensions and not just an environmental concept as widely believed so. In addition to natural resources, sustainability covers economic and social aspects.

2.1.3 Sustainable Development Goals from United Nations

The term sustainability started to gain more attraction with the *Sustainable Development Goals* (SDGs) published by the United Nations in 2015. Figure 2 shows the 17 interlinked global goals in SDG to be achieved by the year 2030. The goals are published with an objective to end poverty, reduce gender inequality, protect the planet, etc. [25]

Figure 2 Sustainable Development Goals [14]

The SDGs are based on decades of work done by the United Nations and countries from all over the world. Figure 3 illustrates a brief timeline story of such work:

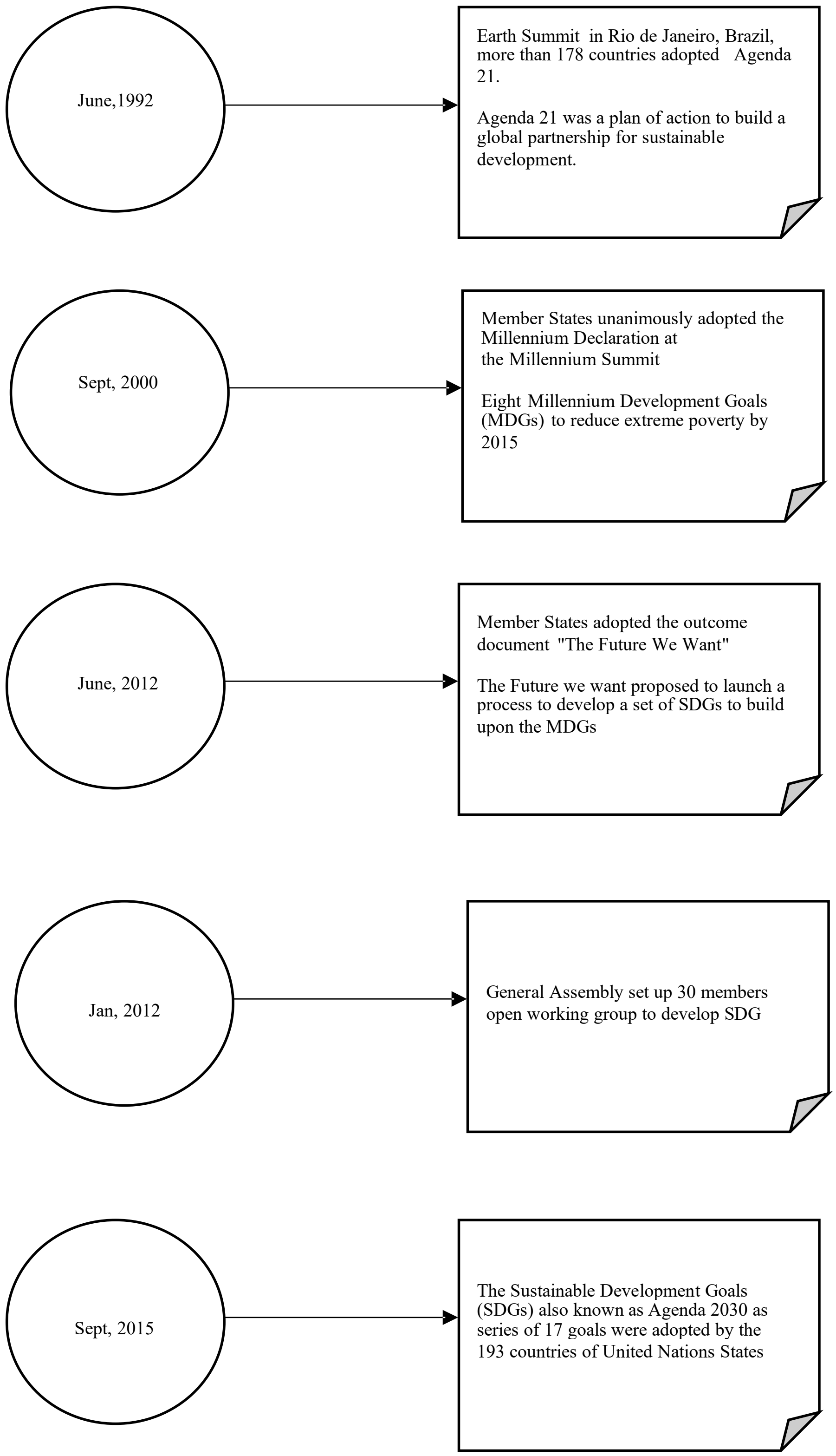

Figure 3 Brief timeline of Sustainability development by United Nations [14]

2.2 Sustainability Performance Indicators

There are numerous papers on categorizing the performance indicators of sustainability. Generally, triple bottom line dimensions are used to evaluate sustainability to measure corporate sustainability performance. A famous British management consultant and sustainability guru John Elkington coined the phrase “triple bottom line” in his book named “Cannibals with Forks”[21][26]. He used this framework to measure the performance of corporate America. TBL was originally an accounting framework. However, businesses have been adopting the principle to evaluate their performance in a broader perspective. Andrew Savitz defined TBL as "captures the essence of sustainability by measuring the impact of an organization's activities on the world including both its profitability and shareholder values and its social, human and environmental capital”[27]. Triple bottom line (TBL) rests on the idea that the company needs to improve people’s live and environment along with making money. Hence TBL has three dimensions – economic, social, environmental. When these dimensions are used separately, they are called one dimension, while a combination of them can lead to two dimensions as did on the articles of Labuschagne et al. 2005 and Sikdar et al. 2003 [28][29].

2.3 Measurement of TBL Dimensions

The TBL dimensions are often called 3Ps – people, planet, profits. The measurement of TBL can be tricky. There is no common unit among the three dimensions. Economic dimensions (aka profits) are measured in units of money. But how can we measure the social impact of the company? What can we do to measure the environmental health of the company? Some people want to normalize all the dimensions in units of money. For example, putting dollar value in employee retention or recycling waste. But such a method could be misleading as it could be challenging to put the right price for such indicators. Another way to measure TBL could be to compare each index with a benchmark index. For example, a company can compare their employee retention and recycling waste with that of the previous year. Therefore, there is no universally accepted standard way of calculating the TBL dimensions. One needs to adopt the framework to measure the TBL depending on the project type, entity, and geographic scope [10].

2.3.1 Economic Dimension

Economic dimensions are often recognized as “generic dimensions”. They embrace the general aspect of the organization to be in the business for long term [30]. Economic success creates the path for social and environmental success. Economics dimension are consisting of measures that can assess the value creation process of a company and its stakeholders in both short and long terms [31]. The economic dimensions of sustainability can contain several components such as:

- Sales revenue
- Inventory
- Cost of capital
- Order process on time
- Inventory optimization
- Maintenance and servicing
- Profit gained
- Annual sales volume

- Income
- Return on investment
- Net profit
- Revenue growth
- Return on assets
- Profit to revenue ratio
- Cost reduction etc.

Sheth et al. (2011) have identified the two distinct aspect of economics sustainability – conventional financial performance such as profit, cost etc. and long-term economic well-being of the stake holders such as standard of living [32]. The two aspect of the sustainability builds a framework for consumer center sustainability. This approach of measurement is useful to find not only the financial performance of the company but also their contribution to the society.

Even though economic dimensions are heavily relied on the financial performance of the company there is more to look into it. Such concept is covered and supported in the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002 and again in Rio De Janeiro in 2012. In the WSSD report, the UN established that economic growth and development are two different terms while economic growth is necessary for development, the development should be prioritized over the growth. The report mentioned the importance of sound economic policies, solid democratic institutions and improved infrastructure are the base for sustained economic growth for the development of poverty eradication and employment creation [33].

2.3.2 Environmental Dimensions

Environmental dimensions include the natural resources and well-being of the eco systems such as quality of air and water, energy consumption, solid/toxic waste landfill wastes etc. The companies want to measure the resource consumptions, waste generations and negative impact of them on land, water and air [34]. Environmental dimensions represent how a company is contributing to safeguard the natural resources and preserve the fundamental functions of the environment. It can help to understand companies view on conserving natural resources and their use. Here are few examples of indicators of environmental dimensions:

- Air emission
- Water emission
- Land emission
- Water utilization
- Land used
- Resource saving
- Hazardous waste
- Waste reduction
- Solid waste used
- Energy utilization
- Fuel consumption
- Noise pollution

Modern companies are moving towards renewable energy and using recyclable materials in the product and the packaging to achieve the sustainable development goals (SDG) by United Nations. The sustainable reports of the companies like Danfoss boast about how their actions are aligned with the SDGs. Since environmental dimensions have direct relationship with that of economy, companies are not stepping behind in using their environmental steps in marketing of a product.

2.3.3 Social Dimensions

Social dimensions include the well-being of a community through education, equity and access to health, high standard of living and other social resources. This dimension is all about the relationship with the stakeholders of the company. Oshika and Saka (2017) surveyed the companies that existed for over 100 years and found that value-added that is distributed to stakeholders other than shareholders is significantly larger [35]. Stakeholders are the people who are in a direct and indirect relationship with the organization such as employee, consumer, legal and government entities, and society at large [30], [31], [36], [37]. Some examples of social indicators are:

- Employee training
- Employee turnover
- Employee diversity
- Repeat customers
- Occupational health and safety
- Community outreach engagement activities
- Local community hiring percentage
- Total number of complaints from local community
- Community satisfaction
- Product satisfaction rate
- Number of customer complaints

2.4 Mass Customization

Consumers' behavior changing than what it was a decade ago. Customers are not happy with standard service anymore. They want to see more variety while they are looking for T-shirts, sneakers, socks, cellphone and whatnot. They want different variety for their parents, spouse, children, friends etc. They want high-quality service/products customized for them and they are no longer willing to wait for them. With the increased use of the internet, standing on the line is an old fashioned way of shopping. With the rise of fintech industries, it takes few seconds to order something from an online store and takes few days to get it delivered to the door. Who has the time to drive to a store and buy a pair of socks that will also have their dog picture imprinted on them? They are no longer happy with standard service and want to see customized service immediately unlike the products that took months to deliver in the last decade. Such customer behavior changing the business strategies of modern businesses. Every company that want to scale are looking to customize their product/service to some extent.

2.4.1 Mass Customization vs. Mass Production

Mass customization (MC) enables the customers to get products tailored to their requirements to some extent. As opposed to the "made to stock" concept, mass customization means shifting the production process to fit as many customer requirements as possible. MC is a challenge against the traditional manufacturing process and supply chain. Unpredictable demand, compatible products, logistics, etc. are the biggest challenges for companies to scale mass customization and make a standard solution. Process agility, flexibility and integration in the current product life cycle make MC harder to adapt for a company. Table 1 shows the difference between Mass customization and Mass production (MP) [38]:

Table 1 Brief Difference between Mass Production and Mass Customization

Mass Production (MP)	Mass Customization (MC)
Benefits: Definite repetitive task can result in low-cost standard goods and services	Benefits: Companies can configure how to satisfy more customers by capturing more customer feedback
Challenges: Unable to satisfy all customer segments	Challenges: Requires the supply chain to be flexible and hard to scale. Longer delivery time creates frustration among customers.

2.6.2 Examples of Mass Customization

There are several small and medium startups are working solely on mass customization. For example, Printful, Printify, Teespring, Gooten are the print on demand online store that offer customer designed merch delivered to their door. Printful store offers customization of men, women, kids clothing and accessories. Under the men clothing, they have different type of clothing. Each of these clothing can be customized according to customer preference of color, style of print and size. What makes it interesting is the customers can upload their own logo, text to be printed on the cloth. The T-shirt delivers in 8-10 business days [39]. Figure 4 depicts how Printful is customizing products in five steps:

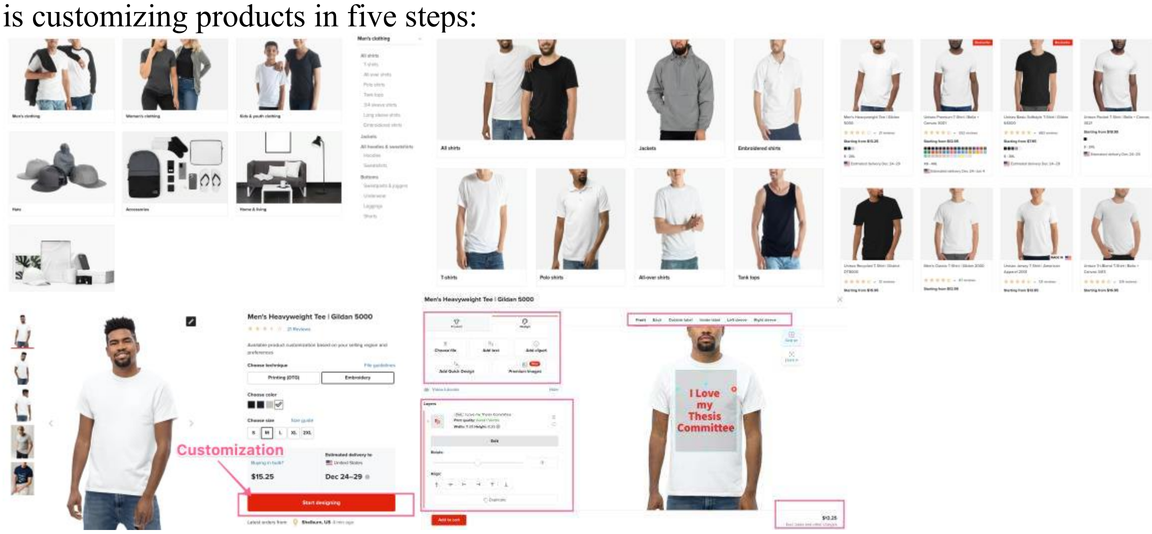

Figure 4 Customer can customize in these 5 steps. 1. All type of products that Printful offer customization. 2. After selecting "Men's Clothing" the website shows different type of Men's Clothing 3. After selecting the "T-shirts, the website will offer different kinds of T-shirts 4. After selecting the "Men's Heavy Weight Tee", the website will give different sizing options and a tool to design. 5. Different customization options on the design tool

2.4.3 Product Configurator

Mass customization companies like print-on-demand stores are taking the advantage of the advancement of information technology. When a company wants to mass customize with a lot of variety of offerings, they need to integrate the system in a way so that customers can interact with all the departments of the company. Without such integrations, it would take months for a company to customize a product for a particular customer. Most importantly, it is hard to scale for the company. The technology that integrates the supply chain of a company is called a *Product configurator*. The product configurator answers the fundamental questions of a company while offering mass customizations. In real time, the company needs to check the inventory of the basic components that need customization, validity of engineering the product according to customer order, the delivery time of such customization. The company needs to quote a price from the decisions of such questions. Product configurators are integrated with the ERP systems. The configurator needs to communicate with BOM (bill of materials), master planning, supplier availability, cost, and price to configure the right quotation of the product [40].

2.4.4 Classification of Mass Customization

Pine 1993; Lampel and Mintzberg 1996; Gilmore and Pine 1997; Duray et al. 2000 have developed different classification models of mass customization [10], [41]–[43]. Even though the models are different, all the models are based on when the customer is involved in the supply chain. The customer involvement point is a crucial business strategy for any MC companies. Customer involvements point in any stage of product life cycle effects the following stages.

Duray et al. (2000) divide mass customizers into four groups: fabricators, involvers, modularizers, and assemblers (Table 2). In the fabricator group, the customer is involved in designing the product. The product is cut to fit according to the demand of the product. The involvers stage means the customer is involved with the designing and fabrication but there is modularity in assembly and use. The customization is achieved by assembling standard modular components of the product according to the specification. Customer can choose the design from standard components and manufacturer fit the product according to the design. Since the involver stage uses modularity, the economics of scale can be achieved higher than fabricators. Involver stages maintain a high level of customer engagement too. The modularity stage means that modularity happens in the design and fabrication stage and the customer are involved in the assembly and delivery stage. At this stage, the companies have products that use common components. For example, a furniture manufacturing company may use the same modular component for all of their sofas. However, the customer can choose the fabric or wood finish in the assembly stage of the production. They have nothing to do with the design or fabrication stage customization. In the assemblers stage, both customer involvement and modularity occur in the assembly and use stage. Customers can choose from a predetermined set of features presented as a wide range of choices. Assemblers are closely related to mass production manufactures. However, they are different in the fact that customers can specify which products to assembles according to their demand. For example, customer can choose the various configuration of PC from Dell website. It makes customers believe that the PC will be customized according their needs, which gives Dell a competitive advantage [43].

Table 2 Types of Mass Customization (Duray et al. 2000)

Type of Modularity				
Point of Customer Involvement	**Design**	**Fabrication**	**Assembly**	**Use**
Design	Fabricators		Involvers	
Fabrication				
Assembly	Modularizers		Assemblers	
Use				

Stump et al. (2009) made another category on top of this type of mass customization (Figure 5) – low level mass customization and high-level mass customization [44]. With high level mass customization, the customers are involved in the design and fabrication stage in the fabricator and involvers strategies. Having customers involved in the early stage of the value chain, makes forecasting of demand difficult, less economics of scale, less lean manufacturing and requires higher flexibility. However, the profit margin of high-level mass customization could be significantly higher. On the other hand, the low-level mass customization, customers are involved in the assembly and delivery stage in the modularizer and assemblers strategies. In such a scenario, the design and fabrication steps of the product life cycle are not changed at all. In this case, the economy of scale becomes easier to achieve and accuracy of forecasting demand is close to mass production. It gives more lean manufacturing capability.

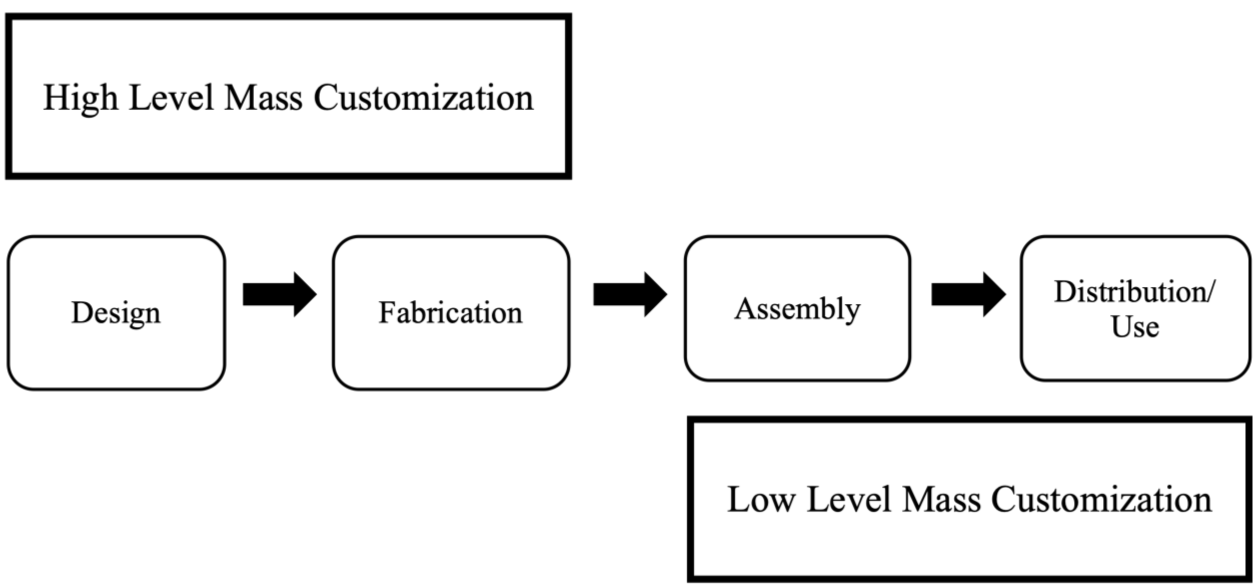

Figure 5 High and Low level of Mass customization Stump et al. (2009)

Based on the literature, the Table 3 highlights the key difference between high level MC and low level MC:

Table 3 Difference Between High Level MC and Low Level MC

High Level Mass Customization	Low Level Mass Customization
High Flexible Manufacturing system needed	Low Flexible Manufacturing system needed
Complex production Planning. Master planning and Bill of materials could be unique.	Production planning relatively easier. Master planning, bill of materials are close to mass production
Higher Employee engagement with higher creativity.	Low employee engagement with low creativity.
Higher Customer loyalty	Relatively lower customer loyalty
Design to order customization takes a higher lead time	The modular design helps to lower the lead time
Lower return policy for customers	Flexible return policy

We can further categorize the MC based on the production approaches.

1. Engineering to order (ETO)
2. Make to order (MTO)
3. Assemble to order (ATO)

If we make another category in the middle of the High-level MC and Low level MC we can derive a relationship between the production approaches and the customization categories as represented in Figure 6.

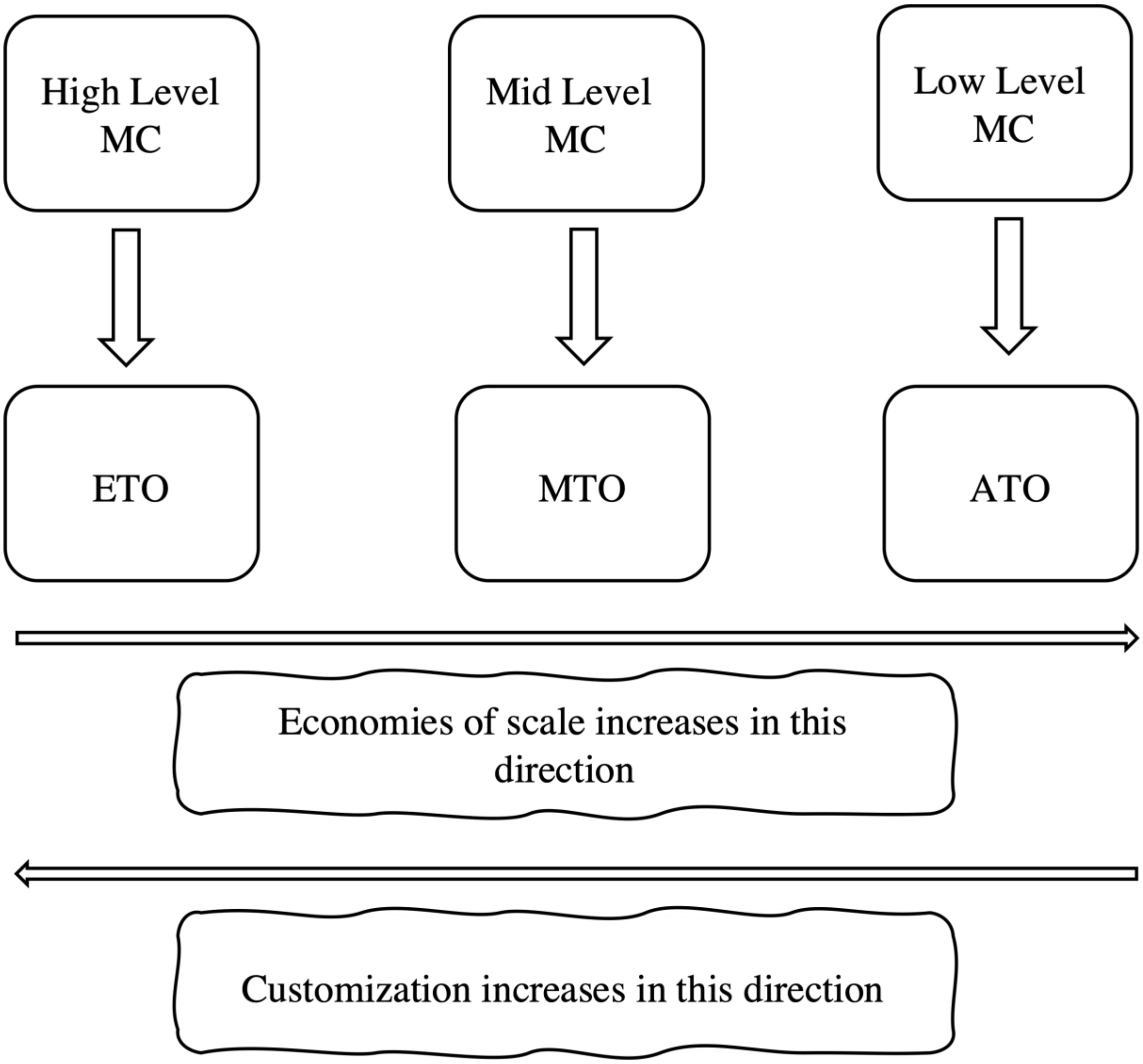

Figure 6 Relationship of type of customization with Business Strategies

Medium level MC does not build a product from scratch for the customers like in the high-level customization. Medium level MC is comparable with make to order business approach where the business customize the specification of the product to some extent on demand of the customer but never produces from the design stage. The customers can change the style of the product such as color of the components of the sneakers or a custom print on a T-shirt/socks. However, the business will not produce a different sneaker or a different material T-shirt/socks for the customer.

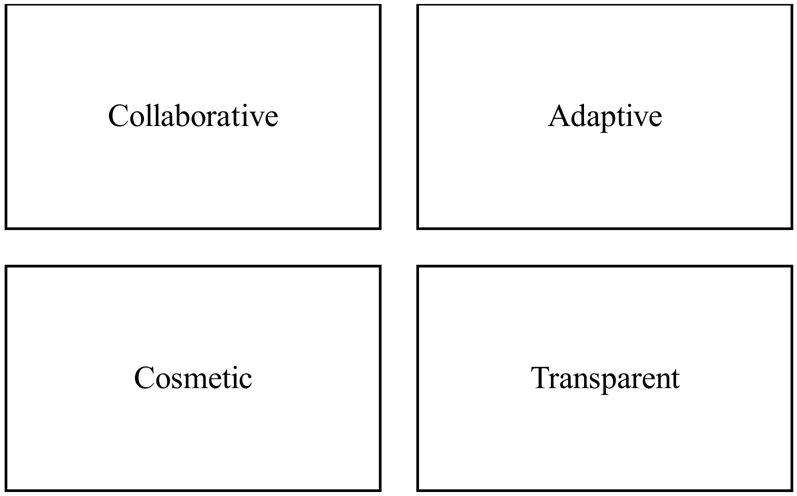

Figure 7 Four Faces of mass customization Gilmore et. al (1997)

On another study, Gilmore et. al (1997) identified four different approaches of MC (Figure 7) [10]:

1. **Collaborative Customizer:**

As described before, companies like Printful use a product configurator to take customers input on clothing size, color, custom logo etc. Then they send the information to their customer nearby production facility to manufacture and deliver the clothing to the customer. This kind of customization is called collaborative customization.

2. **Adaptive Customizer:**

In adaptive customization, the customers are sold one standard product, but the product is customizable after the sale. For example, Apple sells standard iPhones. But the customers can buy the accessories like the cover, cases, etc. to customize the phone. If the software is open source like android, then the customers can customize the operating system too according to their preference.

3. **Cosmetic Customizer:**

In cosmetic customization, the companies sell standard products with different ways or in different packages. For example, Coca Cola sells the same soda in a bottle (plastic and glass) and can at different prices. The cover and cases of phones can fall under this category too.

4. **Transparent Customizer:**

Transparent customization means the customers are provided without their explicit knowledge that the company made some customization in their products/services for them. For example, Facebook is tracking the different preferences, attributes, locations of a user and showing them ads based on them.

An illustration of all the different types of MC and the approaches along with different business strategies, is depicted in Figure 8. Transparent customizer and ETO are on the high level of mass customization happens and Collaborative customizer and MTO are on the medium level. They happen in the design and fabrication stage. ATO on the low level of mass customization happening at assembly stage. Cosmetic customizer and Adaptive customizer represent that customization can occur between mass production and consumer use too. However, there will always be stage even before the high level MC where a product is personalized in small quantity for few particular customers. This kind of personalization happens when a customer orders a private jet or a luxury car like Rolls-Royce. However, it is beyond the scope of this thesis and was not considered.

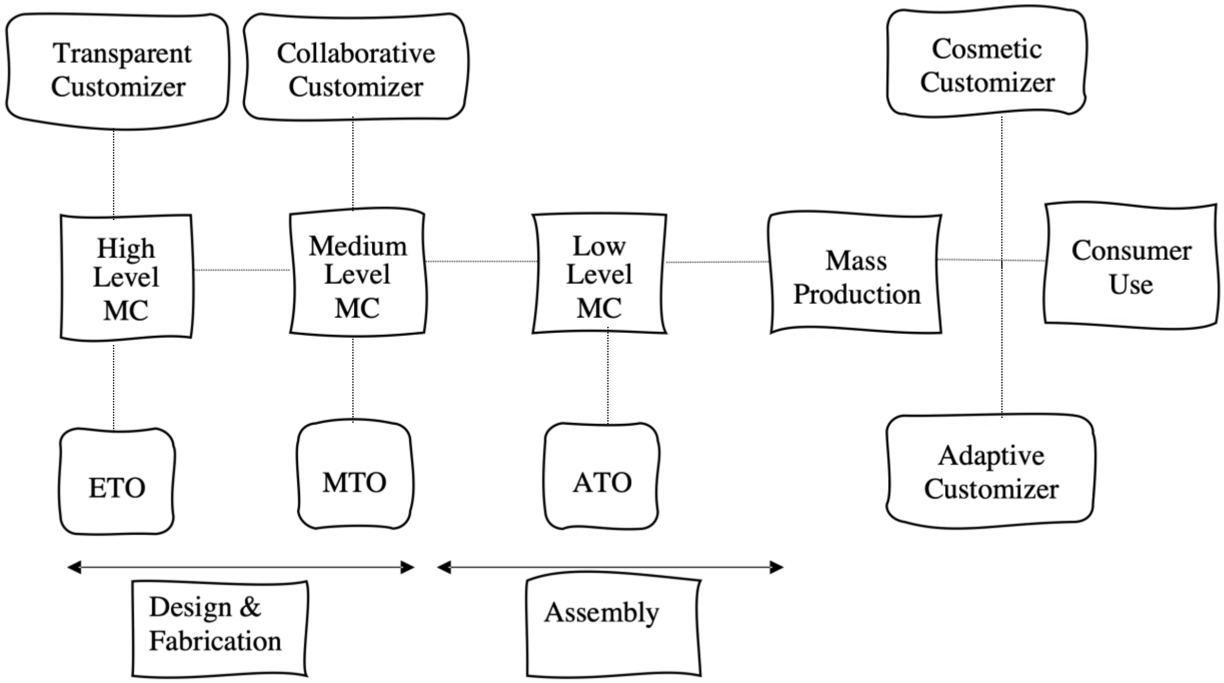

Figure 8 Mass Customization Classification with respect to different stages of Mass Customization

2.5 Key Performance Indicators of MC

Mass customization depends on several important metrics. To be a successful mass customization company, a business needs to ensure a lot of things based on their business strategy as described above. Depending on whether the business is pursuing high-level MC or low-level MC, these metrics are changed significantly.

2.5.1 Modular Product Design

Modular product design means subdividing a part into various components that can be independently produced. Those components can be used to make numerous other variations of the main part. In order to make a modular design, product designers need to decompose various product and find a common component among them. The designers can group the components naming the module. They can modify the module when they need to change the design of the product or make another variation of the product. The modularity concept was first introduced by Star (1965) [45]. The author proposed modularity as a new concept of creating variety.

The main advantages of modularity are [46]:

- Design flexibility
- Augmentation
- Cost reduction
- Lead time reduction

Since mass customization encourages individualized variety manufacturing, modularity is a discipline that every MC company needs to learn. Mass customization requires high skilled workers forcing the companies to hire skilled professionals or train their employees with quality education.

2.5.2 Flexible Manufacturing system with Supplier

Since mass customization creates a lot of variety in products, they require the production system to be as flexible as possible. The company needs to adapt to production changes, change in lead time, and cost of changing the system. Sometimes, the company may need to produce small volume products. It is hard for a company to be efficient in low volume manufacturing and apply lean and just in time (JIT) principles. Then again, the company needs to postpone assemble to provide ATO customization. None of these are possible without a strong supplier relationship. With a strong and broad relationship with the suppliers, the company can reduce its risk in mass customization and increase profitability with the application of lean and JIT systems.

2.5.3 Integrated Information System/Product Configurator

To successfully scale customizations, a company needs to be responsive to any order placed. They need to be flexible in changing system and act together. Sales, Marketing, Logistics, Engineering, etc. divisions need to be integrated together to fulfill an uncertain order. To overcome challenges like these, a company needs efficient information system to ensure the communication among the departments be smooth. To automate the system of the quotation process, MTO and ATO companies are using a product configurator. A product configurator is a tool/software that helps the customers configure the product according to their specifications and get the quote of the product instantly. The product configurator can reduce lead times, fewer errors, few learning curves, etc. However, building a product configurator could be difficult and require high technical skills. The more automation is wanted, the more difficult it will be to build a configurator [47]. On the other hand, ETO companies need to quote the price based on the demand. Product configurator does not work with ETO companies as they do not have real time data available for an instant quotation. However, ETO companies work with B2B companies with bulk orders unlike MTO and ATO companies[48].

2.5.4 3D Printing and Mass customization

Additive manufacturing has revolutionized the rapid manufacturing process. It is attracting growing interest to scale the mass customization process. 3D printing can help companies to move from mass production to mass customization smoothly. 3D printing can unlock new customizable options for customers [49].

Benefits of 3D Printing for Mass Customizations [50]:

- Customer Driven Manufacturing: Customer can designed/specified product can be built into CAD file and the CAD file can be converted to 3D printable files like STL (Standard Tessellation Language) for fabrication.
- Integration of design and manufacturing: 3D printing ease the integration of design and manufacturing

- Flexible: 3D printing is flexible to handle all product variations and does not need to change any tool setup like traditional manufacturing tools.
- Noise Free Production: Less tooling required in the 3D printing allows quieter production and fewer emission.
- Inventory Elimination: Since 3D printing encourages print on demands, it can allow smaller batch production and eliminate the need for the warehouse and inventory keeping.

Despite all these benefits, there are still few challenges of integrating additive manufacturing in the production process. For example, the lack of high skilled workers and expensive 3D printers hinder such an approach of mass customization.

2.6 Research Gap Analysis

2.6.1 Motivation

The growing attention to sustainability issues caught the attention of the researchers to investigate them from different perspectives. Several authors developed a model to identify and systemize KPIs from TBL dimensions, product life cycle phases, unit measurement, etc. All the models varied based on the industries whether they are service business or manufacturing. As mentioned above, mass customization is also becoming a popular concept to develop closer customer relationships. Even though the concept of MC developed decades ago, the concept is getting more attention these days from companies as they are trying to adopt Industry 4.0. In the era of industry 4.0 and additive manufacturing (3D Printing), mass customization seems very achievable.

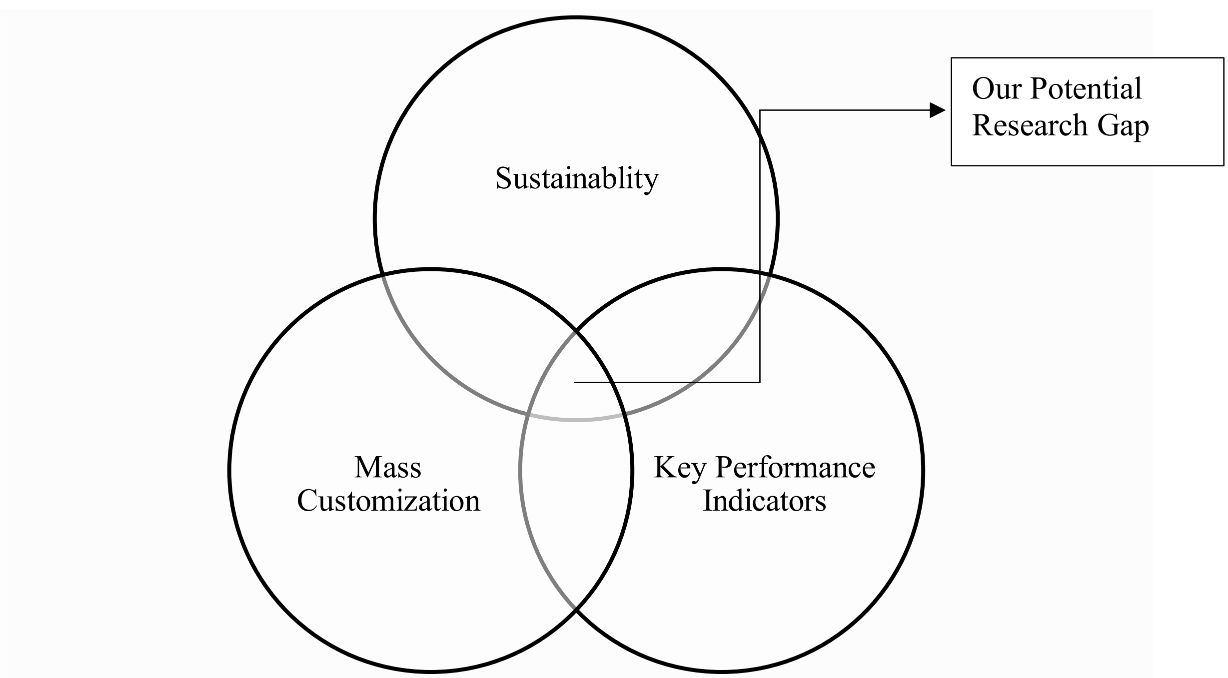

Figure 9 Research Gap Analysis

2.6.2 Research Questions

Based on that, the research gap of this thesis was established (Figure 9) as there were no research found to knowledge that worked on the key performance indicators of sustainability in the mass customization companies specifically. Numerous studies that explore the sustainability KPIs in different manufacturing industries. But none of the research develop any standard set of KPI model that can go with all the manufacturing industries. Besides, none of the research focused on the relationship between the sustainability KPIs of mass production and mass customization companies.

Within this context, the research aimed to identify how the key performance indicators (KPI) of the mass production is related/not related with customized manufacturing considering triple bottom line dimensions. The research question that are sought:

- RQ1: What are the standardized set of KPIs on different mass manufacturing industries?
- RQ2: How those KPIs of the mass manufacturing are related to customized manufacturing industries?

To address the first research question, a literature review methodology is developed. After the selection of the papers the KPIs from the papers are listed. Since the TBL is popular in systematically categorizing the KPIs of sustainability, the papers that are used TBL dimensions were used as a screening criterion for papers.

The thesis paper contributes to update the existing literatures in two ways. First, the paper contributes on building a standardized model from the KPIs of different manufacturing industries in TBL dimensions. Then, the thesis builds a relationship of the KPIs from the mass production with mass customization. An illustration of the thesis structure is described in Figure 10.

Based on the analysis of research gap, a literature review methodology was designed. The following chapter will describe the methodology in details.

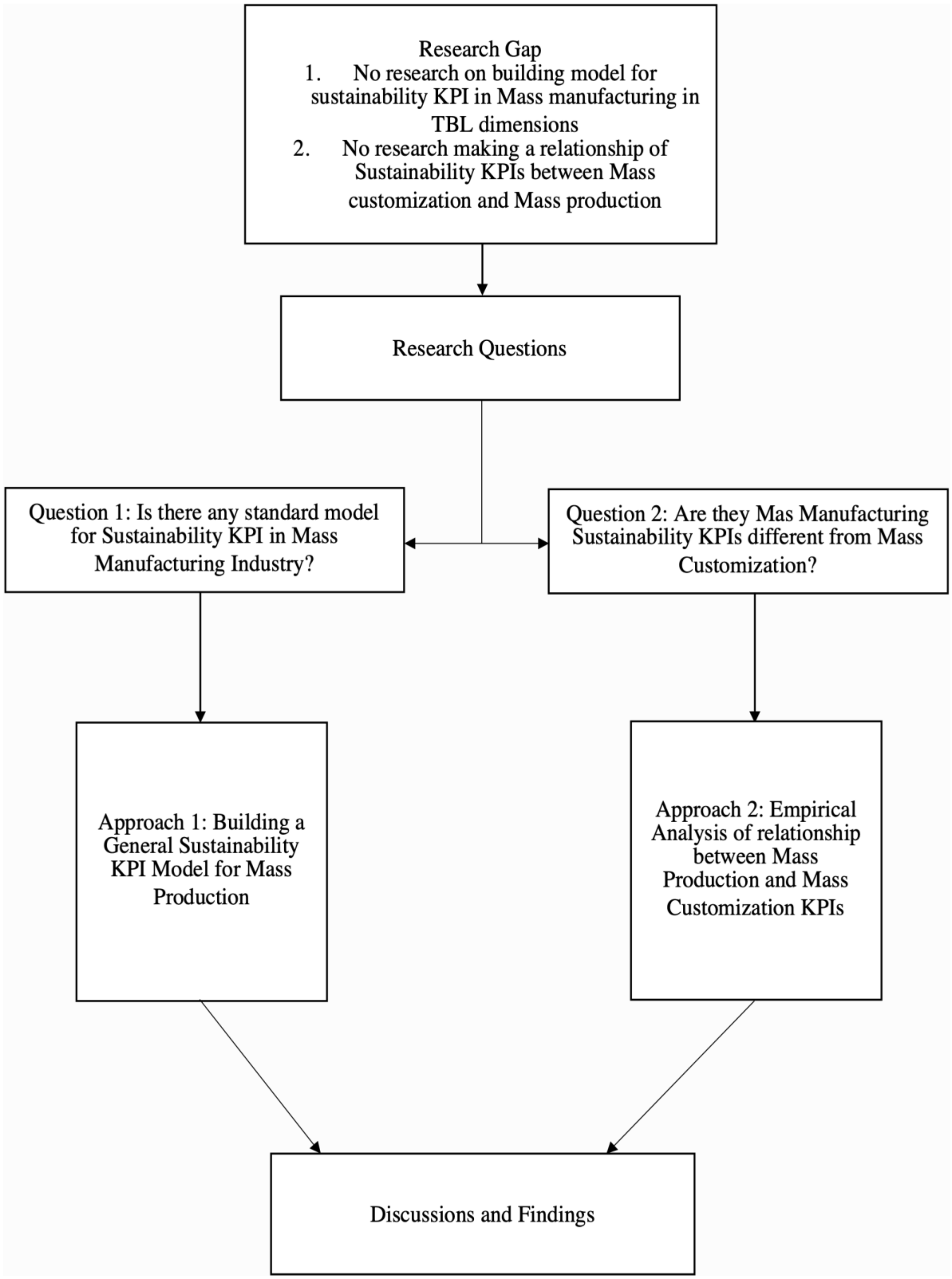

Figure 10 Thesis Structure

3. Literature Review Methodology

The research study is followed a systemic literature review process. A search string was constructed to find the relevant papers. Initially, the database was selected to find the papers. Scopus has coverage for a large number of journals. Therefore, only Scopus was used. Initially, Scopus showed 131,147 search results for Sustainab* and (manufactur* or "production"). The symbol "*" in the keyword (Table 4) covers all the keywords associated with it. However, most of these papers were not relevant. Since the study is focused only on KPIs of the sustainable manufacturing, different synonyms of KPIs used in papers were used to find the publications. At last, there were 1,779 papers without any duplicates from the search string as described in Table 5.

After that, the titles of papers were studied to find 105 assumed relevant papers for this study in different industries. The screening criteria was to find KPIs in different manufacturing industries structured in triple bottom line dimensions. The abstract and in some cases full paper was studied to find 23 papers. Then, forward and backward search of these 23 papers is being done as represented in Figure 11.

It is important to mention that no other filters such as *Source title*, *Year of Publication*, or *Document type* was given at any time. A brief summary of these papers are given on Table 6.

Table 4 Frequently Used Keywords in the documents

Keyword	Coverage
sustainab*	sustainability; sustainable; sustainable consumption; sustainable innovation; sustainable operations; sustainable systems
Manufactur*	manufacturer, manufacturing, manufacturing companies, manufacturing performance, manufacturing industry, manufacturing technology

Table 5 Initial Search Results and Filtered Documents

Search Term (sustainab* and (manufactur* or "production")) (Date: October 1st, 2020)	**Total Publication**
"performance metrics" and sustainab* and (manufactur* or "production")	115
"key performance indicators" and sustainab* and (manufactur* or "production")	244
"KPI" and sustainab* and (manufactur* or "production")	121
"Performance indicators" and sustainab* and (manufactur* or "production")	648
"performance measures" and sustainab* and (manufactur* or "production")	184
"Performance Assessment" and sustainab* and (manufactur* or "production")	882
Total without duplicates	***1779***

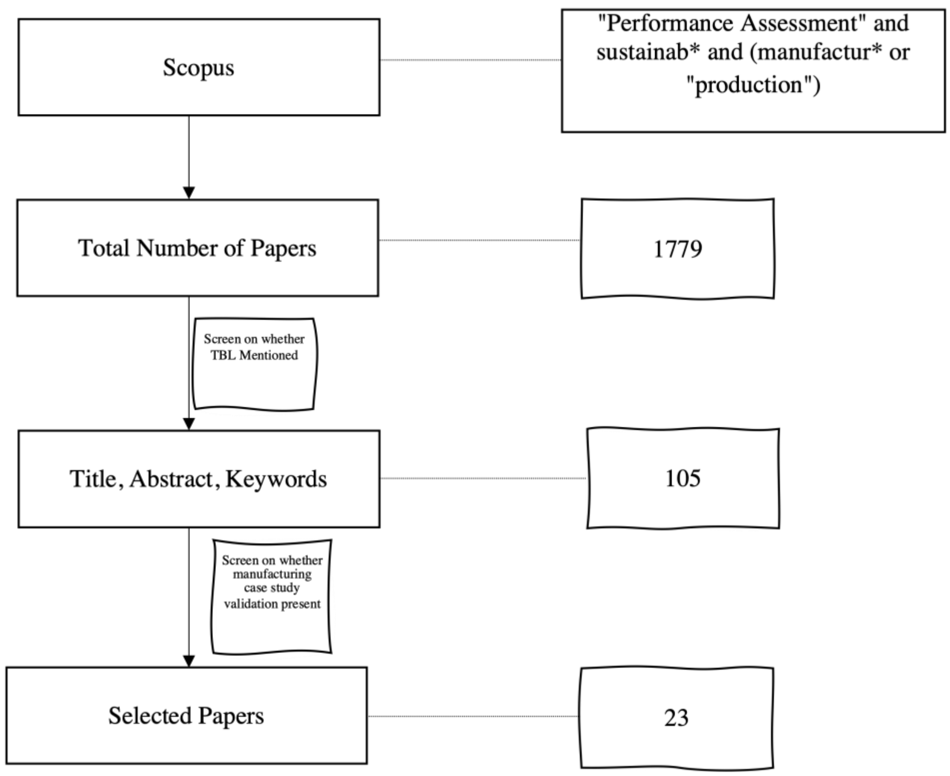

Figure 11 Application of Inclusion Criteria

Table 6 Summary of the Papers based on critical KPI and their relevant industry

Author	**Number of KPIs**	**Critical KPI**	**Case Study**	**Industry**	**MC/MP**	**Type of Publication**
Huang et al. (2017)	49	Economic	Yes	Local Consumer Electronic	MP	Conference
Kusrini et al. (2019)	30	Economic (Order processing on time)	Yes	Leather	MP	Conference
Sangwan et al. (2019)	52	Social (Factors related to employee)	Yes	Cement	MP	Journal
Amrina et al. (2011)	41	Social (Relationship with supplier)	Yes	Automotive	MP	Conference

Amrina et al. (2015)	19	Economic (Inventory Cost)	Yes	Cement	MP	Conference
Amrina et al. (2018)	17	Economic (Preventive Cost)	Yes	Rubber	MP	Conference
Elhuni et al. (2017)	19	Economic (Revenue Growth)	Yes	Oil and Gas	MP	Conference
Strezov et al. (2013)	-	Environmental (Pollutant emissions)	Yes	Iron and Steel Making	MP	Journal
Sari et al. (2015)	78	Environmental (Total of Lubricant Consumption)	Yes	Automotive	MP	Conference
Reddy et al. (2017)	18	Economic (Material Cost)	Yes	Paper Manufacturi ng	MP	Conference
Zackrisson et al. (2017)	-	Environmental	Yes	Shop floor level Swedish Industries	MP	Conference

3.1 Literature Summary

Huang et al. (2017) focused on building a performance measurement framework based on TBL (Economic, Environmental and Social Impacts), 6R (Reduce, Reuse, Recycle, Remanufacture, Redesign and Recover) and total life cycle focus (Premanufacturing, Manufacturing, Use and Post use). The authors developed their Enterprise sustainability index (EnSI) on their product and process sustainability metrics. EnSI has a five-level hierarchical structure in the sequence of individual metrics, sub clusters, clusters, sub index, and the index. The sub-indexes are the triple bottom line dimensions, and the metrics are derived from different literature. A local consumer electronic company was analyzed to validate the EnSI model [51].

Kusrini et al. (2019) found 30 KPIs- 12 economical, 10 social and 8 environmental indicators in sustainable warehouse for leather manufacturing industry. The authors identified the KPIs from literature and surveyed five experts in the field to identify the weights of the KPIS using an AHP process. The most important weight was given to economic factors followed by Social and environmental. Order processing on time, Occupational health and safety, Energy storage system got the highest ranking on economic, social and environmental aspects respectively [52].

Sangwan et al. (2019) presented a framework for sustainability assessment that not only covers the TBL but also covers the organizational policies, products and process. In total, they identified 121 indicators from the literature by performing frequency analysis of important performance measures. Then the indicators were tested on Indian cement industries through Likert chart scale survey of the experts in the field. From the 153 responses received, the authors identified 52 indicators (including product, process and policies) that are suitable for cement industry from empirical study [53].

Amrina et al. (2011) carried out literature survey to identify nine dimensions of 41 KPIs initially in automotive industries and incorporated them to TBL perspective. Economic Indicators were based on the four manufacturing performance indicators (quality, cost, delivery and flexibility). Social and Environment indicators are derived from literature too. A three-part questionnaire was developed to validate the initial KPIs and sent to two group of experts. From the nine responses received they reformed the questionnaires to conduct a full survey for the Malaysian automotive companies [54]. Amrina et al. (2012) built on the previous study and analyzed the interrelationship of the KPIs using an interpretive structure model to find 5 out of those 9 indicators are unstable and require high attention from the automotive managers [55].

Amrina et al. (2015) did a similar study on the cement industries to find 19 KPIs from the literature. Then the KPIs were validated through five points liker scale survey of the twelve managers of an Indonesian cement manufacturing company. Based on the survey the authors found Material cost to be the most important indicator followed by energy consumption, inventory cost and occupational health and safety having same weight. The six indicators having the lowest weight were removed. Then the authors evaluate the 13 remaining KPIs using the AHP analysis. After establishing a hierarchy, the pairwise comparison questionnaire (with a consistency ratio) was designed to survey ten senior managers from the cement industries to find the weight of the indicators. Economic factor was considered to be the most important factor in the cement industry with material cost having the most weight. Three plants of the cement manufacturing company were presented based on the evaluation model [56]. Amrina et al. (2014) applied interpretive structure model to find a structured network between the 13 KPIs in the cement industry. There were no indicators with interrelationship. But the four indicators (Raw material substitution, Energy consumption, Fuel consumption and Material consumption) are found to be the driver of the rest of the indicators [57].

Amrina et al. (2018) performed similar study in rubber industry where 17 KPIs were derived from literature review. Then a liker scale survey was conducted among Six managers of Indonesia to find the weights of the KPIs. An interpretive structure model was applied on the 13 most important indicators to find the relationship among them. Environmental Factors with four indicators (Energy consumption, Lighting and Ventilation, Emission and Working environment) found to be the driving factor in the rubber industry [58].

Similar study also done by Elhuni et al. (2017) where the authors identified the 19 KPIs of sustainable production in oil and gas industries through literature review based on triple bottom line dimensions. Then 25 managers were surveyed using a liker scale to find out the weights of the KPIs. Revenue growth was found to be most weighted indicator followed by profit to revenue ration and net profits. Based on the results, five indicators were removed and the remaining 14 KPIs were evaluated by a AHP analysis. Then five managers were surveyed with a pairwise questionnaire using a consistency ratio. The results show that economic factor is the most important factor with net profits being the highest indicator. Then the model was applied on a Libyan oil industry to show different performance level of the three fields [59].

Strezov et al. (2013) studied the emissions of three major technologies of iron and steel production to compare the sustainability parameters. The parameters of emission were normalized in economic parameters to evaluate the sustainability performance compared to coal fired electricity production and wheat production. Energy consumption, CO_2 emissions, water consumptions and land use were ranked sequentially to be the most the prominent indicator of sustainability in iron and steel production companies. SO_2, NO_x and CO were found to be the most prominent pollutants [60].

Sari et al. (2015) developed a questionnaire to survey 15 experts in the Malaysian Automotive companies. The authors categorized the KPIs based on TBL in 8 perspective and 78 measures under them. From the 78 measures, Total of lubricants consumption, Overall plant effectiveness, Stake Holders- Company partnership came out to be the most important measures. Learning and growth and stakeholder's relationship was the most important values among the eight perspectives and social indicators had highest mean of important values among the three indicators [61].

Kibira et al. (2017) proposed a framework for developing the KPIs of sustainable manufacturing. The five steps of this framework described as KPI identifications from literature and if there any gaps exist, then defining the KPIs from a top down or bottom-up approach, KPIs selection from surveying the managers and compositing the KPIs in the same scale of measurement. The framework was applied on powdered metal manufacturing process. The six candidates identified to achieve the sustainability goal of the manufacturing were material efficiency, virgin material efficiency, CO_2 emissions, N_2O emissions, energy per part, and energy efficiency. Energy part had the highest important vales after the three managers were asked to weight those KPIs [62].

Reddy et al. (2017) identified 18 KPIs from the literature for paper manufacturing industries. Then 5 managers from the production department were asked to rate the indicators. The authors used the technique for Order of preferences by similarity (TOPSIS) to ideal solution methodology to evaluate and normalize the factors. The model is validated by a case study of three plants with their sustainability assessment [63].

Zackrisson et al. (2017) investigated the KPIs at shop floor level in Swedish manufacturing companies. The results showed 90% of the indicators found are related to TBL and 26% of them are directly related to environmental factors [64].

Singh (2016) developed a framework for Malaysian SMEs based on the TBL and found 12 key performance indicators. To evaluate the model the hierarchical fuzzy inference system was used which can output a sustainable performance measure after users input weight of each indicators [65].

The next section of the thesis focuses on building a general sustainability KPI model for mass production.

4. General Model for Sustainability KPI

4.1 Selection of KPIs

From the reviewed papers, approximately 300 KPIs were taken out to make the first KPI list in TBL dimensions. All these KPIs were independent that go under the definition of the inclusion criteria. The duplicators were removed, and a spreadsheet was made to analyze them. Each of these papers worked on a different case study to validate their KPI models. Hence, the industry name is noted too.

4.2 Cluster

Even though every KPI was independent, some KPIs had the same meaning or goal. That helped to make clusters (Figure 12) in the TBL dimension from the large list of KPIs. Goal-based classification of sustainability KPI was adopted in Ivo Histov et al. (2019) paper [66].

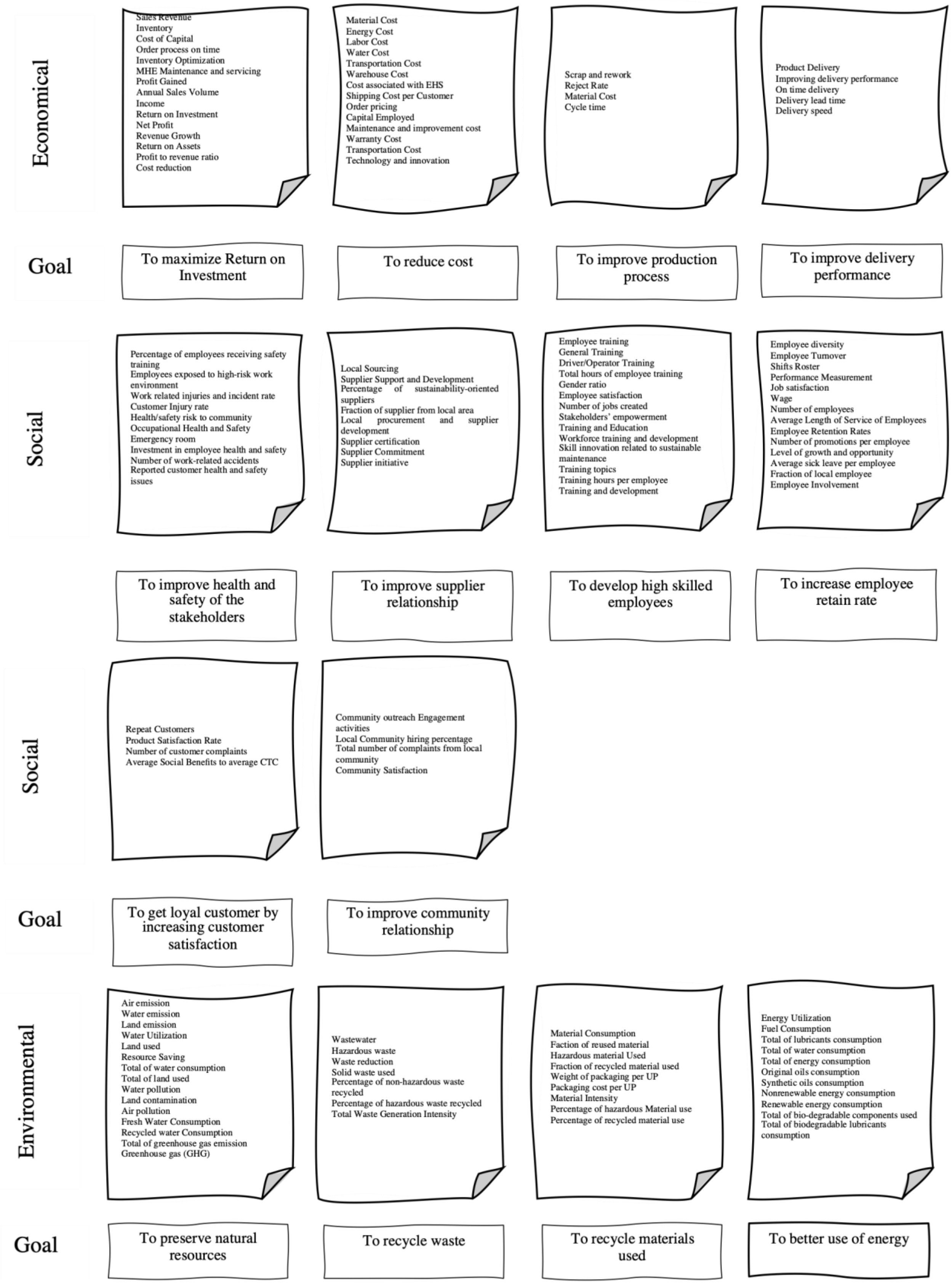

Figure 12 Sustainability KPIs clusters based on their goals

4.3 Sustainability KPI Model for Mass Production

Based on the goals above a standard model of sustainability KPIs is derived for mass production in Figure 13.

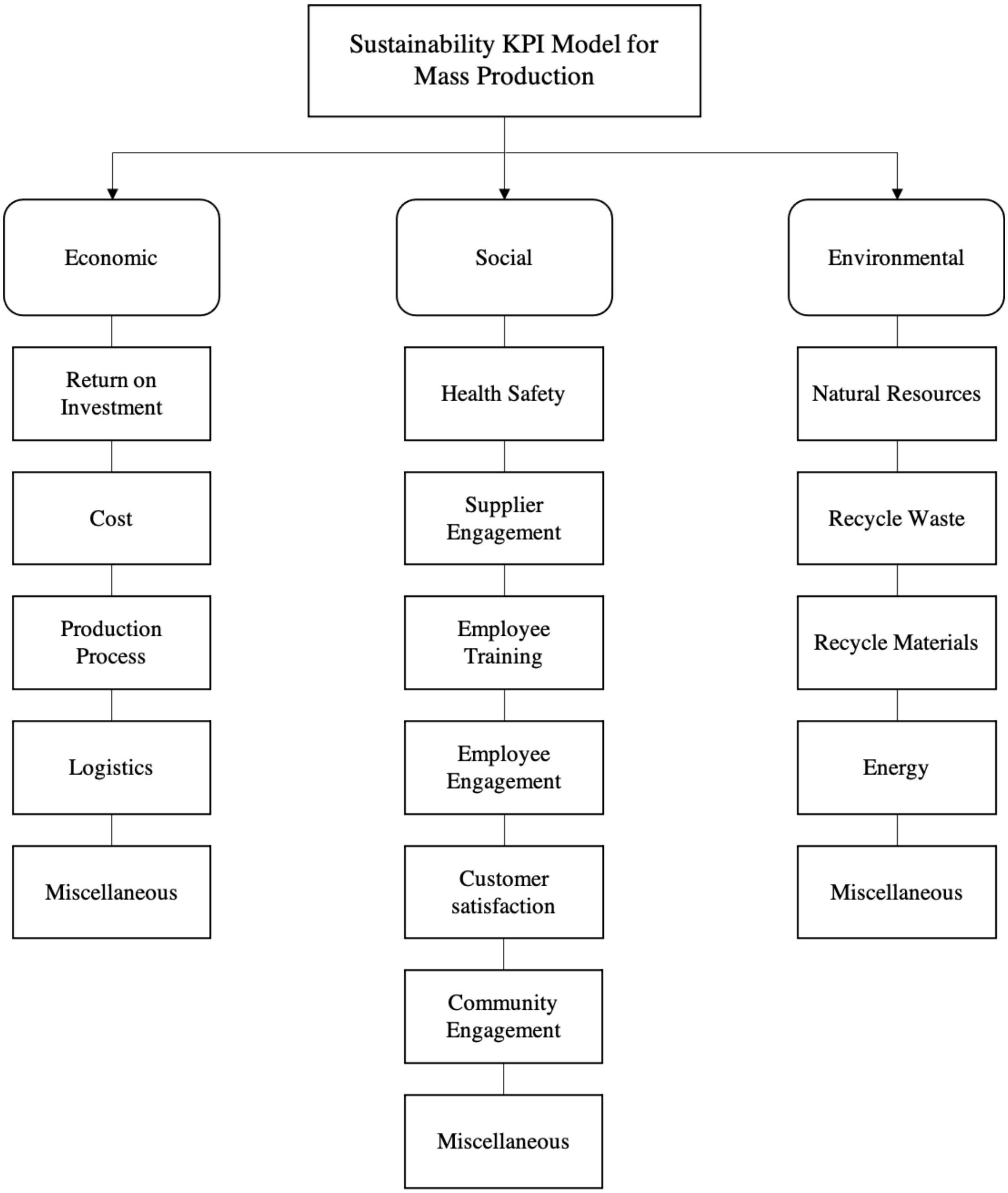

Figure 13 Sustainability KPI Model In TBL

The sustainability KPI model is presented in TBL dimensions. Components of the model cover all the KPIs from the literature regardless of the industry. However, there are some special KPIs that are specific to the industry being studied. For example, the leather industry requires temperature control of the warehouse which may not be the case for other industries. To deal with such KPIs, a miscellaneous component is added to the model.

To start investigating the second research question, Table 7 is constructed to list the most frequent KPIs found in the literature. These KPIs are selected to analyze with the KPIs found from mass customization companies. Note that, the synonymous KPIs were counted as one. For example, product delivery, delivery time, on-time delivery, delivery lead time, delivery speed is counted as transportation cost.

Table 7 Frequent Used Mass Production KPIs

Economical	**Social**	**Environmental**
Revenue	Employee training	Water Consumption
Material Cost	Occupational Health and Safety	Energy Consumption
Energy Cost	Job satisfaction	Material Consumption
Labor Cost	Employee Involvement	Land utilization
Water Cost	Gender Equity	Air Emission
Transportation Cost	Employee Turnover rate	Noise Pollution
Warehouse Cost		Hazardous waste
Tax		
Inventory		
Customer Satisfaction		

The next section of the thesis will use three case studies to identify the sustainability KPIs for mass customization. Those KPIs will be analyzed with respect to the mass production KPIs.

5. Case Studies

To validate the standardized model of the KPIs in traditional manufacturing, three different mass customization companies from three different sectors were analyzed. Nike, Dell, and Danfoss are found to be among the mass customization companies that publish sustainability reports yearly. Since there is no published research found on the Sustainability KPIs of these companies, the case studies are designed from different research published on these companies and the KPIs are driven from their sustainability report.

5.1 Nike By You

One of the most established footwear company Nike launched its mass customization production in the name of “NikeID” in 1999. It allowed the customers to design their footwear. Nike released a mobile app in 2012 that allowed regular customers to design and buy shoes from their app. NikeID rebranded itself to “Nike By You” to be more expressive for customers by offering more customization options [67].

Nike By You offers customizations in different categories – basketball, running, lifestyle, baseball, football, soccer, etc. for both men and women. Using the Nike By You web app, a customer can design the upper, collar, tongue, swoosh, tape, stitch lining, laces, flywire, heel clip, sockliner, insert, outsole and tongue text/logo of the Nike Metcon 6 (Figure 14). Each component of the shoe can be customized in 12 different colors. Custom-made Nike Metcon 6 is $150 and delivers in less than 5 weeks. However, the standard designed Nike Metcon 6 comes in $130 and deliver within a week [68]. (price based on March 26, 2021)

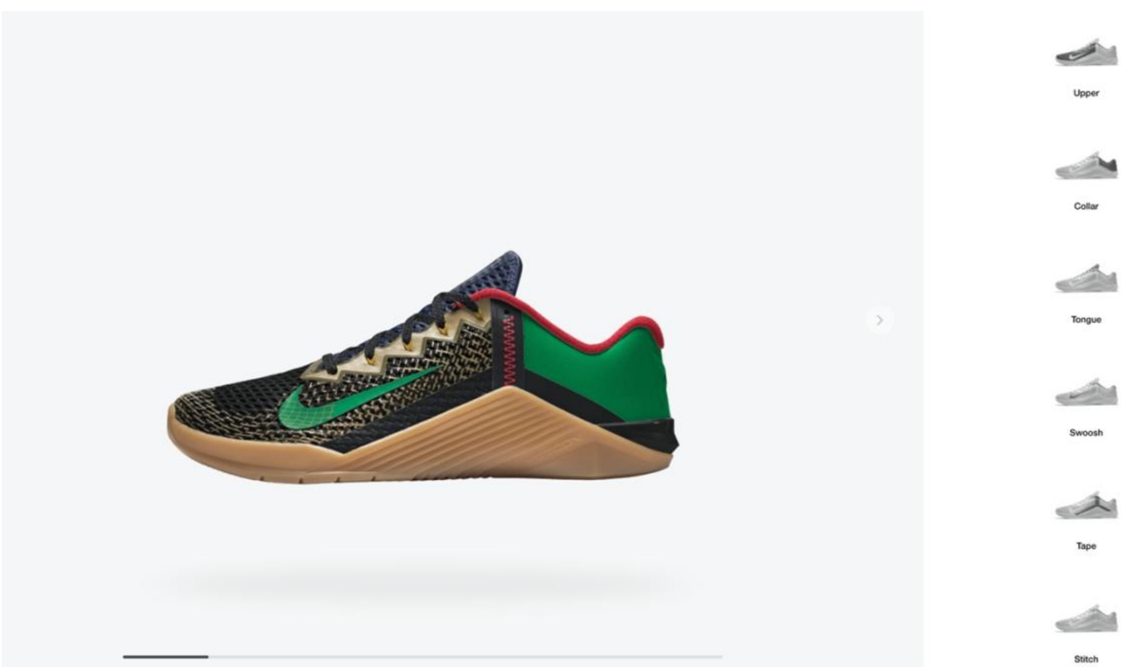

Figure 14 Nike Metcon 6 Customisation Dashboard from Nike By You

5.1.1 Nike By You KPIs

The three-dimensional KPIs were extrapolated from the FY16/17 Sustainable Business report by Nike in the Table 8. These KPIs were drawn from the priority issues and performance targets of Nike in their sustainability report [69].

Table 8 Sustainability KPIs of Nike By You

Economical	Social	Environmental
Sustainable Materials	Child Labor	Chemicals used in production
Logistics	Excessive Overtime	Energy and emissions
	Freedom of association	Materials consumption
	Attracting and retaining talent	Materials waste
	Occupation Health and Safety	Water consumption
	Total compensation	Average Product Carbon Footprint
	Workforce Development	Renewable energy
		Carbon consumption
		Carbon Emissions

5.2 Dell

Dell is one of the largest companies in PC industry that offer mass customization to customers. Using internet technology, Dell offers a product configurator that customers can use to customize their own PC/Laptop. Customers can interact with the website to configure the PC from the different options provided. A product configurator allows customers to accurately entry their requirements without needing validation from an engineer. Dell shares these configurations with all of their department and follows the make to order and assemble to order policy to make the customized laptop. A flexible manufacturing system with cooperative suppliers, employees, distributors allows Dell to offer many customization options. By offering customized PC, Dell is increasing their value proposition for its customers and suppliers while maintaining overall profitability. A customer can customize the processor, operating system, graphics card, memory, hard drive, color, and display of the Dell XPS desktop (Figure 15). The product price will vary from $1449-$2509 with delivery in six weeks as of March 26, 2021 [70].

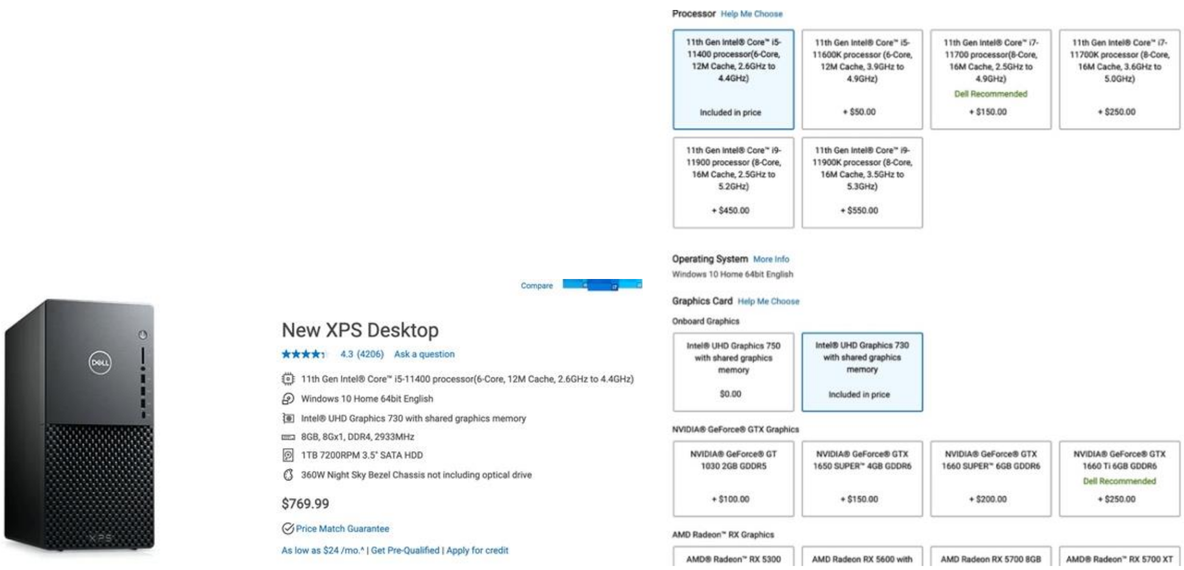

Figure 15 Dell XPS Desktop Customization with product configurator

5.2.1 Dell KPIs

The three-dimensional KPIs were extrapolated from the FY19 Corporate social responsibility report by Dell in Table 9. These KPIs were drawn from analyzing their 2020 goals dashboard [71].

Table 9 Sustainability KPIs of Dell

Economical	Social	Environmental
	Community Service	Water Risk Mitigation
	Quality Education	Renewable Energy
	Gender equality	Waste Diversion
	Leadership inspiration	Energy intensity of products
	Inclusive culture in employees	Recyclable Materials in products
	Flexible work options	Recyclable Materials in packaging
	University hiring	Environment Sensitive Materials
	Team member satisfaction	Recover used electronics
	Sustainable Supplier Sourcing	

5.3 Danfoss

Danfoss is a Danish multi-national HVAC product manufacturer. While they sell standard products in their stores and website, they offer customized products for each business. For example, Danfoss can produce customized mechanical drives built to specific customer orders (Figure 16). These drives are shipped all around the world. Since most of the products is customized Danfoss follows a designed to order stock policy for its customized solutions. The pricing, delivery time depend on the customized product, order size, and the business. It is important to note that Danfoss is a B2B company, they tailor their manufacturing process according to the business order. Therefore, Danfoss does not have any standard delivery time and pricing like Nike and Dell. They quote their pricing and delivery time for each business separately.

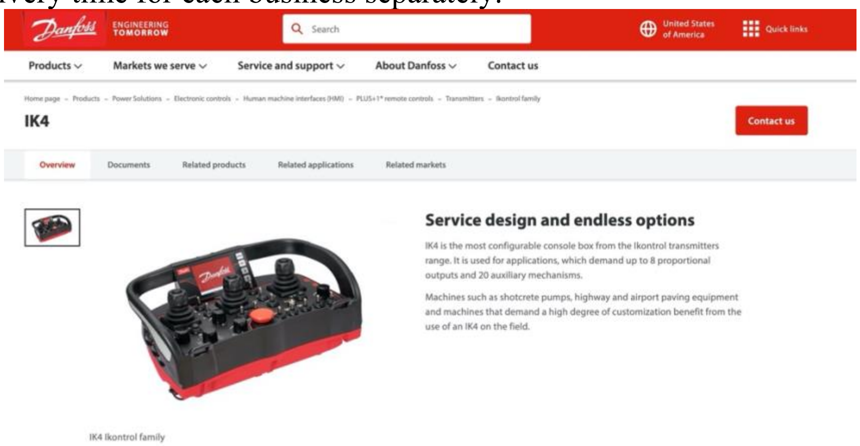

Figure 16 Danfoss IK4 Customization [58]

5.3.1 Danfoss KPIs

The three-dimensional KPIs were extrapolated from the sustainability report 2019 by Danfoss in Table 10. These KPIs were drawn from analyzing their commitment to sustainability essay [72].

Table 10 Sustainability KPIs of Danfoss

Economical	Social	Environmental
Products and Materials	Female Leadership	Zero CO2
	Lost Time Injury	Energy Intensity
	Diverse Teams	Energy and CO2 Emissions
	Employee engagement and commitment	Resource Efficiency
		Energy Efficient Water System
		Maritime sector emissions

In the next section, the KPIs from these three mass customization companies will be analyzed with respect to the frequently used KPIs from the mass production as described earlier.

6. Discussion and Findings

The KPIs derived from the sustainability reports show similar KPI components as traditional manufacturing. However, there are differences in the weights of some of the KPIs between mass customization and traditional manufacturing. The discussion below highlights the difference between the Sustainability KPIs in Mass customization and Traditional Manufacturing.

6.1 Revenue In Mass Customization Can Be Higher Than Traditional Manufacturing

Nike By You sells customized shoes at a higher premium than their standard products available for buy at the store right away (Table 11). The product takes less than five weeks to deliver when the standard products take around a week. It shows that customization allows Nike to sell a shoe for a higher premium. As a result, the revenue of Nike goes up when they sell customized shoes. However, there is not much information to understand whether mass customization increases their profit margin or not. The customized shoes require a skilled employee to produce the shoe according to customer demand. Also, the product will be shipped separately as opposed to standard shipping. Therefore, there is an extra labor hour and processing fee for a customized shoe. Thus, the profitability of the customized shoe depends on the supply chain efficiency of Nike.

Table 11 Comparison of Standard and Customized Nike Shoe Price

Shoe Name	Standard Product Price ($)	Customized Product Price ($)	Premium over Standard Price	Reference
Nike Free RN 5.0 2020	100	120	20%	[73]
Nike Metcon 6	130	150	15.38%	[68]
Kyrie 7 "Brooklyn Beats"	130	150	15.38%	[74]
Nike Mercurial Vapor 14 Elite FG	250	270	8%	[75]
Nike Alpha Huarache Elite 3 Mid	95	125	31.5%	[76]

However, the revenue in the mass customization depends on how much customization is done by the company. Nike By You offers “design to order” customization where a customer can make a shoe according to his preferable color and design. Then Nike By You needs to design the shoe according to the customer order. But Dell offers “assemble to order” customization via their product configurator of the website. Customers can pick the customization options of the PC and the product configurator automatically quotes the pricing of the product based on the configurations. For example, the standard XPS desktop comes in $769.99 with 8GB memory. If a customer wants to upgrade memory, there will be $100, $250, and $550 extra for 16GB, 32GB, and 64GB respectively. When a customer orders a high configuration PC, a skilled employee from Dell will need to assemble the order. However, Dell is not charging any higher premium for such customization [70]. Figure 17 illustrates that MC reflects an improvement over MP in the *Revenue* dimension.

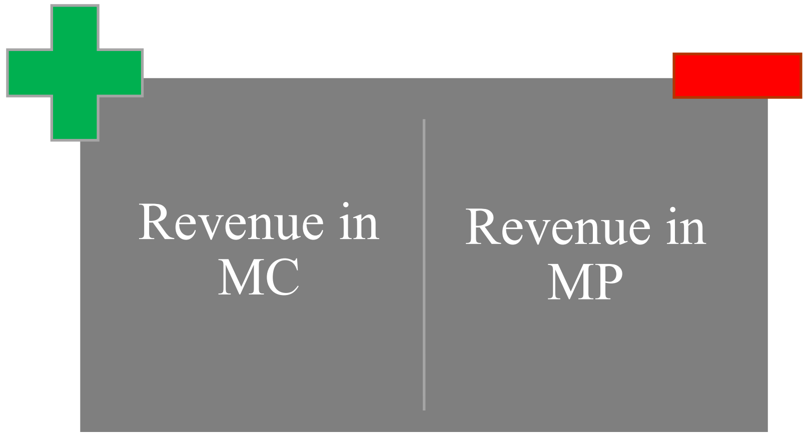

Figure 17 Revenue in Mass Customization can be Higher than Traditional Manufacturing

6.2 Raw Material Needed For Mass Customization And Traditional Manufacturing Are Same

Nike sources the same raw materials from the suppliers as they do in traditional manufacturing. The main difference between standard shoes and customized shoes lies in the customized colors of the several components of a shoe. Therefore, Nike needs to source the same number of components of a shoe from their supplier [77]. For example, the Nike Metcon 6 has 14 components to customize. The colors of the shoe will be customized by a skilled operator according to the customer demand after the order is placed on the website. Nike will have no effect in sourcing the 14 basic components of the shoe from their suppliers, only the colors will be customized according to the demand. Similarly, Dell source the same number of PC components from their supplier as they would in traditional manufacturing. The customization configured by the customers in their website has no effect on their sourcing PC components from their suppliers [68].

Sourcing similar raw materials allow the companies to take advantage of the economics of scale as they take in traditional manufacturing. They can buy bulk materials cheaply and take advantage of raising the price of a product. However, sourcing for traditional manufacturing could be better forecasted than MC as they cannot forecast how much customized order they would get on a shoe. But they can forecast the total number of customizations i.e., how many skilled operators/suppliers they need. Figure 18 illustrates that MC reflects no improvement over MP in the *Raw material cost* dimension.

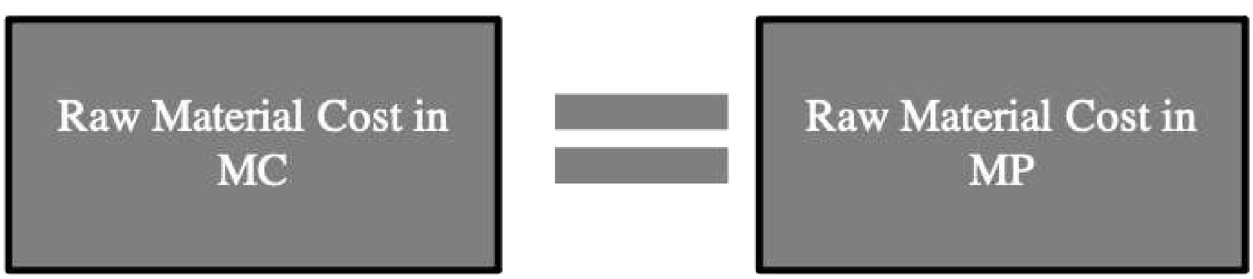

Figure 18 Raw Material needed for Mass customization and Traditional manufacturing are same

6.3 Self-Designed Products Increase Value Of Product And As A Result Generate A Higher Willingness To Pay

According to a study, made by Forbes in 2015, Nike could raise their overall margin by 1.4% from 2014 to 2015 in each shoe as the customers are willing to pay a premium for the custom shoes. "Direct to Consumer" sales were up from 22% to 30% in 2015 too. Thus, launching NikeID (older name of Nike By You) contributed a lot in their revenue by integrating customers in the design process [78].

In addition, Franke et al. (2010) paper studied the several perspectives of involving customers in their design process aka The "I Designed It Myself" Effect [79]:

- Customers build a personal relationship with the product that they design.
- Customers have a higher subjective valuation of the self-designed product.
- Self-Accomplishment motivates the customers to pay a significantly higher price for the products designed by them rather than standard professional items.
- Higher design freedom has a higher willingness to pay.

According to the book "Marketing 2.0 – Strategies for closer customer relationship" by Corbae G et al. (2003), the fastest way to build customer loyalty is to customize every offering of a company. Cultivating customization can bring a company long term customer commitment along with a profitable relationship. By creating a customized product, a company learn from the customers and build a customer-oriented company [80]. Figure 19 illustrates that MC reflects an improvement over MP in the *Customer Satisfaction* dimension.

Figure 19 Self-designed products increase value of product and as a result generate a higher willingness to pay

6.4 Customer Engagement Is Higher In The Supply Chain Of MC

Customers act as co-designer while designing their products through product configurators. It gives them self-accomplishments and motivations. In Nike By You, the Customer can choose the shoe, change the color of all the components of the shoe and make it individualized increase the value of the product to the customers. Customers feel more important and creative while having fun customizing a shoe. Customers become an integral part of the supply chain of the company. On the other hand, companies like Dell can attract more loyal customers by offering the product configurator. They do not need to forecast the standard PC products like other businesses. They can simply do forecasting on the modular components like graphics card, chip, display, etc. They do not need to carry standard unit inventories too. As result, it becomes a win-win situation for Dell. They get higher customer engagement by reducing the cost of warehousing fees. Figure 20 illustrates that MC reflects an improvement over MP in the *Customer Engagement*.

Figure 20 Customer Engagement Higher in MC

6.5 Employee Engagement Is Higher In MC Through Their Integrated Product Configurator

When a customer interacts with the product configurator of the Dell website, he is interacting with the different sectors of the companies. The product configurator allows the customer to process the order in real time. Therefore sales, marketing, finance, logistics, billing, etc. departments need to integrate their operation to fulfill a customized order. MC forced the employees to work in a team and the engagement in the team motivates the employees to perform better. Figure 21 illustrates that MC reflects an improvement over MP in the *Employee involvement and Employee Training*.

Figure 21 Employee Engagement Higher in MC

6.6 Flexible Manufacturing System Increases Supplier Relationship

Mass customization requires a flexible supply chain network as each customized order could be different. The flexibility will depend on the extent to customization the company is offering. Engineer to order companies like Danfoss requires to manufacture a customized mechanic driver according to the customer order. It requires Danfoss to customize their process from the product design stage of their supply chain. On the other hand, assemble-to-order companies like Dell will need a less flexible manufacturing system. However, Dell will need to have a flexible supplier network to cope up with the fluctuating customization orders. "Pull system" of customization makes the procurement difficult not only with the supplier network but also with the internal stakeholders. The company needs to run separate processes simultaneously to produce the configured product by the customer. Figure 22 illustrates that MC reflects an improvement over MP in the *Supplier Relationship*.

Figure 22 Flexible Manufacturing System Increases Supplier Relationship

6.7 Job Satisfaction Higher In MC

Employees are crucial if a company wants to offer MC as employees carry first-hand knowledge of the product. They know how to customize the product exactly the way the customer wants. They can provide useful feedback on the customization to the companies. Therefore, it is important to measure their satisfaction while providing MC. Nahmens, Isabelina & Bindroo, Vishal. (2011) designed a study to test the hypothesis of employee satisfaction in MC [81]. They surveyed key decision-makers of 150 institutionalized home producers and asked them the average percentage of production labor turnover. The metric is considered a substitute for employee satisfaction. Quality improvement programs like employee training and incentive pay programs were control variables of the study. The result of the study showed that the higher the level of customization the higher the employee turnover rate is. Therefore, employee satisfaction is directly related to the level of customization. It shows that not only do the customers feel accomplished while designing a product also the employees feel satisfied by producing a customized product. Higher-level customization could be very complex and daunting which challenges a creative employee to learn more. MC companies need to train their employees more than a traditional manufacturing company as without skilled employees they cannot offer customization as they want to. Trained employees tend to get paid higher and less likely to switch jobs. Figure 23 illustrates that MC reflects an improvement over MP in the *Employee Turnover rate* .

Figure 23 Job Satisfaction Higher in MC

6.8 Delivery Time Is Higher In MC

The delivery time of a MC company also depends on the type of customization. When Nike By You takes five weeks to deliver a shoe, Dell takes less than three weeks to deliver a customized PC. On the other hand, mass produced standard shoes take a week to deliver for Nike. Customized products take time to produce and deliver. Therefore, MC products have a higher lead time than mass-produced product. To reduce lead time, Nike By You places somewhat mass customized products in near offshore distribution centers like Mexico. On the other hand, the product configurator helps Dell in modular manufacturing. The modularity in the manufacturing allows Dell to deliver a customized PC at the same time as a standard PC. Datacenter equipment company APC by Schneider Electric was struggling with their engineer to order model delivery time having 400 days [82]. Switching the model to modular-based design and having a configurator at the sales and marketing stage allowed the company to reduce its delivery time down to 16 days. Customers lose attraction while waiting for a product. The waiting time can be considered as a cost for the customer. However, the customers actively working on the product configurator increases the value of receiving the product. The customers are willing to wait to some extent from the standard time. This explains the five weeks delivery time of the Nike By you. Customers can receive the show within a week if they order the standard model. However, they are willing to wait five weeks for a shoe individualized by them. Figure 24 illustrates that MC does not reflect any improvement over MP in the *Delivery Time* KPI dimension.

Figure 24 Delivery Time Higher in MC

6.9 Customer Return Rate Is Lower In MC

As stated earlier, Customers feel self-accomplished while designing a product. Therefore, they should be less motivated to return a product. Any statistics on the customer return rate of mass customized products could help present this argument, however, analyzing the return policy of the customized products of a company can show how flexible a company is to offer customization services. Nike By You offers 60 days free return policy [83] and Dell offers 30 days return policy to remove the hesitation of the customers from ordering a customized product [84]. It's interesting to see Nike By You accepting the customized styled "never seen before" shoe return from a customer. As their designed to order supply chain policy makes it difficult for them to sell the shoe to another customer. Similarly, Apple allows returning the iPad and iPhone with engravings [85]. On the other hand, Dell does not face this issue in their 30 days return policy. Dell can easily sell the returned custom PC to another customer who is looking for a similar configuration for a less price. However, for companies like Danfoss who offers engineer to order (ETO) customization, does not offer any return for customized specification order [86]. Customized orders can not be returned and Danfoss does not offer any refund for that. Customer specific product orders can not be canceled even if Danfoss having a higher lead time than their quoted lead time for the project. The return policy of Danfoss makes sense, as they get bulk customized orders from businesses where Nike and Apple may take that loss of the returned customized order of a single customer. The return policy of Nike and Apple remove the fear of a customer placing customized order. Being a B2B company Danfoss can not have that policy. Figure 25 illustrates that MC reflects an improvement over MP in the *Customer Return Rate* KPI dimension.

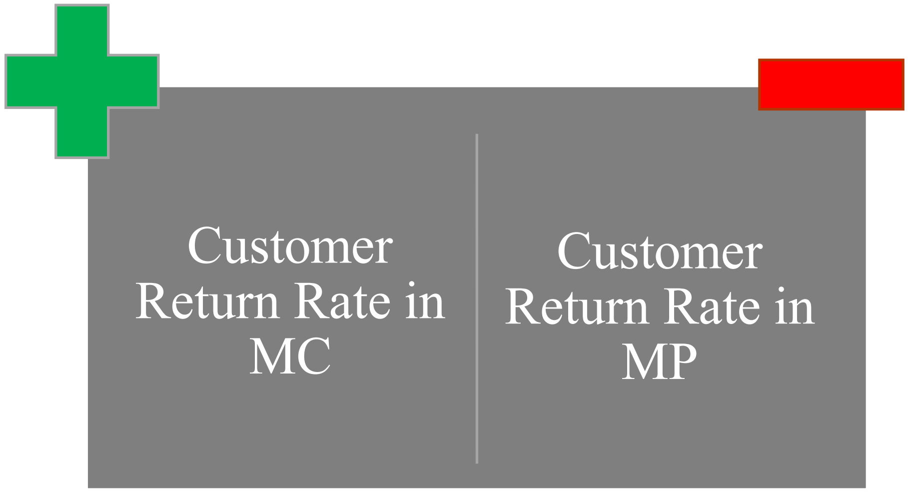

Figure 25 Customer Return Rate is Lower in MC

6.10 Carbon Footprint Is Higher In MC

As stated above, the delivery time of mass customization is usually higher than mass production products. There is no hard evidence on how these customized products shipped. Since customized products may need a separate factory (possibly in a different country) and there is some urgency to deliver them to the customer, the faster way to deliver customized products would be air cargo. It should be noted that global aviation accounts for around 2.4% of global CO_2 emissions that come from aviation. Along with other gases and water vapor trails, aviation accounts for around 5% of the global warming [87]. On the other hand, cargo ships contribute 2-3% of all greenhouse gas emissions [88]. Therefore, if mass customized products are shipped via air cargo by companies to reduce delivery time could be significantly harmful for environment than traditionally manufactured cargo shipped products. But there are some evidence that companies like Nike and others are relocating their customization facilities to near locations like Mexico to reduce the shipping time, even if it is a high labor wage country [89][90]. However, 3D printing allows manufacturing parts locally which reduces the need for transportation via air, water or land. Therefore, the evidence may empirically show that the mass customization has negative impact in the environment, but in the long-term application of 3D printing in mass customization may reduce such negative impact. Figure 26 illustrates that MC does not reflect any improvement over MP in the *Carbon Footprint* KPI dimension.

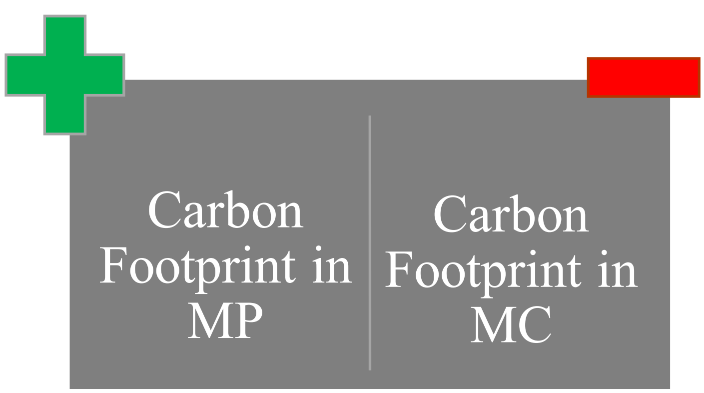

Figure 26 Carbon Footprint is Higher in MC

6.11 Overview Of The Findings

The discussion above validated many indicators from Table 7 that was mentioned in Section 4.3. Figure 27 gives an overview of the difference between the different level of mass customization with mass production.

Tripple Bottom Line Dimensions	KPI	High Level (ETO)	Mid Level (MTO)	Low Level (ATO)
Economic	*Revenue	+	+	=
	*Material Cost	-	-	=
	**Energy Cost	=	=	=
	*Labor Cost	-	-	=
	**Water Cost	=	=	=
	*Transportation Cost	-	-	=
	*Warehouse Cost	+	=	=
	*Tax	=	=	=
	*Inventory	+	=	=
Social	*Customer Satisfaction	+	+	=
	*Employee training	+	+	+
	*Occupational Health and Safety	=	=	=
	*Job satisfaction	+	+	=
	*Employee Involvement	+	+	+
	*Gender Equity	=	=	=
	*Employee Turnover rate	+	+	=
Environmental	**Water Consumption	=	=	=
	**Energy Consumption	=	=	=
	**Material Consumption	=	=	=
	**Land utilization	=	=	=
	*Air Emission	-	-	=
	**Noise Pollution	=	=	=
	**Hazardous waste	=	=	=

+: Better than MP
=: Equal to MP
-: Worse than MP
***: Validated either logically or from papers**
****: Assumptions**

Figure 27 Difference between the different level of mass customization with mass production

All the * marked indicators are discussed above either with evidence from research papers, news articles, or logically. However, the ** marked indicators lack evidence to conclude anything.

The (+) (-) (=) signs indicate whether they are better, worse, or equal when compared with mass production. The figure shows that low-level mass customization has no significant difference from mass production. It makes sense as the economies of scale increase as customization decreases, therefore companies can take the benefits of the mass production. The concept of product configurator can help companies like Dell, Apple, etc. in transitioning to low-level customized services from their traditional production. It helps to satisfy a larger segment of customers with low-level customization and also keeps their operations cheap like in mass production. On the other hand, as the customization level increases, it shows a significant difference with mass production.

However, the figure shows most of the differences in economic and social dimensions. The environmental factors like energy consumption, material consumption, land utilization, noise pollution, and hazardous waste had no evidence and requires deep research to prove whether there is any difference among them. As for this study, there are assumed to be equal.

Some indicators like Tax, Gender equity, Occupational health, and safety needed to no discussion to say that they are equal in mass customization and mass production.

7. Conclusion & Outlook

The objective of this thesis was to find a relationship between sustainability and mass customizations with respect to the triple bottom line dimensions - economic, environmental, and social.

The results show that a general model of sustainability KPIs can be built for both mass production and mass customization industries. However, each KPI has different impact on them. While some KPIs have equal importance in mass customization and mass production, some have greater or less importance.

This thesis contributes to the literature by first presenting a general sustainability KPI framework for mass production that can be applied regardless of industry, second, analyzing the sustainability KPIs associated with mass production compared with the requirements of mass customization to identify existing relationships.

For data collection, the sustainability reports of Nike, Dell and Danfoss were analyzed to derive secondary data from companies that are engaged in sustainable production and (at least partially) mass customization. The KPIs were not directly available in the reports but were derived through analysis of the content. The sustainability reports of these companies did not contain economic performance indicators as they usually publish their economic performances in the financial reports. The sustainability reports were mostly focused on their impact on society and environment. In addition, Nike, Dell and Danfoss are not entirely customization companies. All of these companies have a mix of both customized and mass-produced products. The sustainability reports published by these companies are for all of their product line, customized and non-customized. They do not have any separate sustainability or financial reports specifically for their customization portion of the business. As stated in a previous example, print on demand companies such as 'Printful' are solely focused on producing customized products, meaning their whole product portfolio constitutes customized products/services. However, they are not publicly traded companies and are not required to publish sustainability reports to comply with regulations. For future work, working with selected companies such as 'Printful' with fully customized product portfolio to further validate and update the thesis results.

The KPIs derived in the thesis were considered as one dimensional. Two dimensional and three dimensional KPIs such economics-environmental dimension, economics-social was not taken into consideration at this point. The clusters based on the goals may have some two or three-dimensional effects that may change the standard model of the sustainability KPIs for mass production. However, the two-dimension and three-dimension KPIs could be taken into account for further research study.

The thesis could be further improved if the screening criteria of literature review methodology was relaxed. There is significant research on finding KPIs that did not meet the screening criteria of the thesis. Considering such papers and categorizing them in TBL dimensions could improve the number of KPIs to study before building the model.

Also, the "miscellaneous" component of the model took all kind of manufacturing industries into account. If the thesis focused on a specific industry such as automotive in general, then such component could have been ignored and a more accurate (more specific and less general) model of sustainability KPIs could have been formed. There will always be some KPI that is specific for a certain industry which may not be relevant in another industry. Hence, miscellaneous component is both a weakness and a strength of the model in a sense that it allows for generalization but at the same time reduces fit with individual industries. Hence, in the future, developing industry specific models might be beneficial.

Whenever there is a discussion about sustainability people start thinking about "green supply chain" or environment friendly products. However, filling the research gap among sustainability, mass production, and mass customization was difficult from the environmental perspective due to lack of data/research. The findings of the study were largely focused on the economic and social perspectives. The economic and social KPIs showed significant difference between MC and MP sectors. However, there is no hard evidence to support whether the environmental KPI like fuel consumption varies between MC or MP on a general level. Also, whether the noise pollution, landfill emission, hazardous waste etc. indicators are same for both MC and MP. Therefore, there are more answers to find from the environment perspectives of the mass customization.

The thesis' limitations include the following: Due to Covid-19 impact, there was not any primary data available to validate the case studies. It was not possible to survey or visit mass customization companies to collect primary data within the performance period of this thesis. The thesis can be expanded by surveying key decision makers of mass customization companies and taking primary data from these companies.

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