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Frugal Engineering and its divergence from the common engineering standards

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Abstract- Frugal engineering is not just low-cost engineering; it is a fundamental approach for product development in emerging markets. Frugal engineering adopts a clean-sheet approach that seeks to maximize value for the customer while minimizing unwanted and excessive resource consumption. Companies intending to use frugal engineering in emerging markets must consider economic, technical, and socio-cultural resource constraints. This paper focuses on how frugal engineering diverges from the common engineering approach. We will outline the three conceptualizations of the frugal process and discuss how the frugal process of the supply chain is different from the standard processes of the supply chain, by exploring the three types of archetypes. In addition to it, the three primary criteria that make it possible to distinguish between frugal innovation and other innovations. As well as the key characteristics that differentiate the process. Firms can overcome resource constraints by configuring these characteristics at each stage of their supply chain.

Keywords: Frugal engineering, emerging markets, supply-chain, Frugal innovation, Resource constraints, Frugal process.

I. INTRODUCTION

The term "frugal engineering" was coined by Carlos Ghosn, CEO of Renault, and Nissan, in 2006 to describe the automotive engineering of the world's most affordable car, the Tata Nano. Suzuki, for example, paved the way for the development of low-cost automobiles [1,3]; it is becoming the umbrella term for the process of developing frugal products. These are some of the outcomes of "frugal engineering," a practical and essential approach to developing products and services for developing markets. There may be no better example of frugal engineering than the Nano, which will enable millions of people with limited resources to drive their cars on a regular basis. Unlike many other low-cost vehicles, the Nano is a simplified version of a more expensive car design. Other newly frugal engineered products, from refrigerators to computers to X-ray machines, are based on a bottom-up approach. Frugal engineering is an effective and essential approach to developing products and services. [1].

The primary focus of frugal engineering is to reduce costs and resource consumption. Furthermore, reducing wasteful efforts, incorporating cost-cutting measures into initial production processes, and designing self-invented processes. A critical focus always accompanies a commitment to maximizing customer value on cost. Frugal engineering requires that companies be open to organizational change. Three areas are particularly crucial. Cross-functional teams, an unconventional supply chain, top-down assistance [1,3]. Frugal engineering also occurs in system design and on a large scale. M-Pesa, a mobile banking application, was developed in cooperation with Vodafone in Kenya and is now widely used [2].

Frugal innovation starts with the specific needs of the bottom of pyramid markets then works backward to develop a solution.

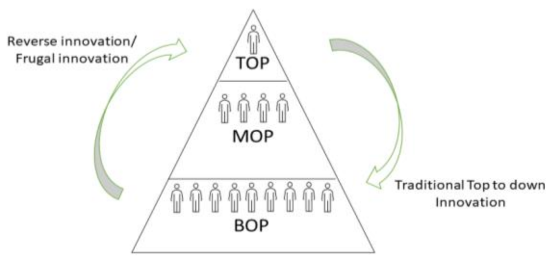

Fig 1. Frugal innovation (bottom-up) vs Traditional innovation (top-down)

As a result, this approach may differ substantially from standard engineering solutions for up-market segments.

In a scalable, sustainable fashion, frugal innovation involves discovering new business models, reconfiguring value chains, and redesigning products to accommodate consumers facing extreme affordability constraints. Creating more inclusive markets must involve overcoming or leveraging institutional voids and resource constraints. The concept of frugal innovation is merely to provide functional solutions for the many people with little means through the use of few resources [4]

At times, the word "innovating" is used in the same sense as "developing." For example. Agarwal and Brem [5, p.37] wrote that companies at the bottom of the pyramid "Businesses started identifying these local innovations more frequently in emerging markets. They realized the special competencies of the local population in innovating cost-effective products, quickly and in a resource-constrained environment"; which was later referred to as "frugal engineering" by Carlos Ghosn, the CEO of Renault-Nissan.

Frugal innovation is sometimes referred to as the term for both frugal products themselves and as well as to the process of developing them [6]. Ojha [6] stated that "the term frugal innovation refers to the systematic innovation process that had been adopted in order to develop high-end, low-cost products." This conceptualization of the frugal process and frugal innovation is expounded better by Julia C. Arlinghaus and Stephanie Knizkov in [8].

II. CONCEPTUALIZATIONS OF FRUGAL PROCESSES

Conceptualization I: Focus on Frugal products

When focusing on frugal products, frugal innovation is aimed to address how the frugal products are developed, rather than addressing what they are (product themselves and their characteristics); a prominent example for product development under constraints is "frugal engineering" [7,8]. The term frugal engineering is often only referred to the process of developing frugal products, whereas the term "frugal innovation" is used to refer to the product themselves [1,8]. Rao gives another example in [9] where he noted that "the design and manufacturing of a frugal product from scratch is assumed to be the primary approach for achieving frugality with the utilization of other features, such as supply-chain and quality-control tests, being secondary or ancillary." However, despite its importance of frugal development, Frugal innovation does more than redesign products; it involves rethinking entire production processes and business models [10]. Hence, the entry for new frugal products in the emerging market condition can be based on the engineering models of the existing products [25;26].

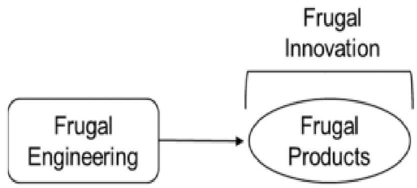

Fig 2. Frugal innovation as frugal products and their Development [8].

Conceptualization II: Disambiguation into a frugal mindset, process, and product

In this concept, Frugal innovation is considered a multi-echelon phenomenon rather than a monolithic entity of frugal products. This typology of frugal innovation made use of frugal products, as well as a frugal mindset and frugal processes, which were widely adopted (see fig. 3) [11]. It considers that resource constraints impact not only product development but also the supply-chain process. A notable example of manufacturing under resource constraints is "Lean Manufacturing," which originated in Japan after World War II. In response to the severe resource constraints, the Japanese automotive industry faced, Taiichi Ohno, the CEO of Toyota, redesigned the company's entire manufacturing system [12]. Some proponents of this approach emphasize the importance of considering all processes in the supply chain, saying that resource constraints affect the entire supply chain, so they shouldn't be studied just in terms of product development [13]. Therefore, frugal products require all the processes associated with them to be frugal as well [13].

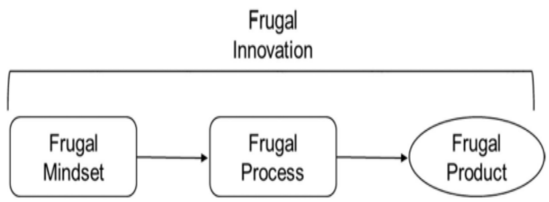

Fig 3. Frugal innovation as a multi-echelon Phenomenon [8].

Conceptualization III: Focus on non-technological innovation

Here Frugal innovation is understood as a non-product and non-technological innovation. Such as frugal business models were already proposed in the seminal paper by "The Economist" [10]. A notable example of frugal innovation of a non-technological nature is the supply chain of the Dabbawalas' lunch-box deliveries in Mumbai, India [74]. The Dabbawalas pick up personalized lunchboxes from their customers' homes, deliver them to their respective offices across the city, and return the empty lunch box to their homes. Through an ingeniously designed color-based code system and using only public transportation and bicycles, the Dabbawalas manage a highly complex network and deliver over 200,000 lunchboxes daily while maintaining an astounding accuracy rate (service level) of 99.99% [14].

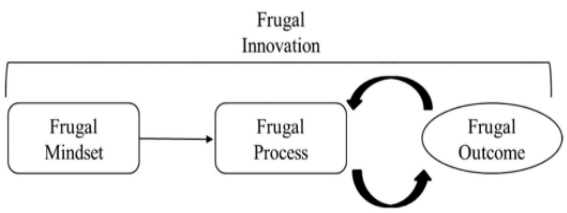

Fig 4. Frugal innovation as a nontechnological Innovation [8].

III. PRIMARY CRITERION FOR FRUGAL INNOVATION

Frugal innovation mainly occurs within the three main categories

1. Substantial cost reduction
2. Concentration on core functionalities
3. Optimized performance level

Thus, most characteristics that are attributed to frugal innovation can be related to at least one of the three primary categories. Using the three categories, we defined criteria for frugal innovation [22].

1. Substantial cost reduction

Frugal innovation is characterized by a much lower price or significantly lower costs compared to conventional products and services. It is not explicitly mentioned whether lower costs must always be from a customer perspective, or innovation can be frugal when there is a cost reduction only from a manufacturer or service provider perspective. Some findings clarify that it must always be from a customer perspective. Cost reductions that only apply to one manufacturer or service provider are insufficient since they do not align with most terms that define frugal innovation. The criterion of substantial cost reduction must, therefore, always be met from the customer's perspective, which includes the view of the manufacturer or service provider [22,23].

It isn't easy to specify the extent of the cost reduction in frugal innovation. Characterizations such as "minimum cost," "much lower price," "significantly lower costs," or "ultra-low-cost" indicate that the cost reduction must be significant for an innovation to be considered a frugal innovation. It is hard to determine a specific threshold value for a substantial cost reduction criterion since there are no representative samples. Based on his comparison, the extent of cost reduction can be calculated between 58 and 97% on an average of 80% [22,23

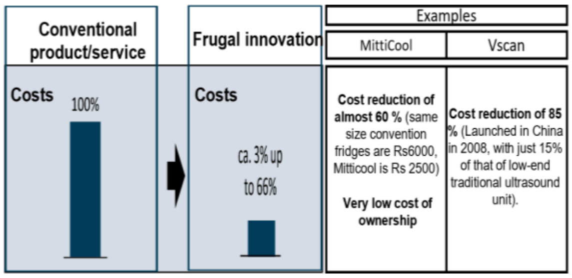

Fig 5. Substantial cost-reduction

]. Concerning criterion 1, From a customer perspective, frugal innovations have significantly lower purchase prices or lower total cost of ownership (one-third or more, price and cost compared to existing solutions on the market, or, if there are no solutions yet, compared to hypothetical manufacturing costs) they are available in the market, e.g., by importing current solutions) [22,23].

2. Concentration on core functionalities

This criterion of frugal innovation is focused on core functionalities, elimination of non-perceived functions, minimalist product features, and user-friendly design [23,26,27,28]. Typically, frugal innovation involves core benefits, essential functions, and reduced complexity. A product or service can be made as user-friendly as possible by concentrating on core functionalities. In this sense, the concentration criterion on core functionalities encompasses all the characteristics above and is a discrete criterion [22,23].

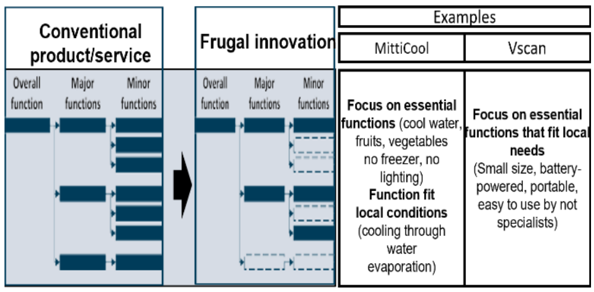

Fig 6. Concentration on core functions

As a result, frugal innovations need to focus on the core functionalities compared to existing solutions. Therefore, the standard concentration of core functions covers all the above characteristics and is a discrete standard. In short, frugal innovation must be at the core Features compared to currently available solutions in the market [22,23].

3. Optimized performance level

Optimized performance level, it is essential if one is to capture the whole meaning of frugal innovation. It reflects the products' capability to meet local environmental needs and is perceived as high-valued and qualitative by the customers [22]. Identifying only core functions is insufficient. There must also be a deep examination of how to determine what levels of performance and quality are required. The engineering characteristics for which the performance level must be determined differ from field to field. In addition to frugal innovations, other innovations as well, not just frugal innovations, require serious examination of their performance levels. There are two reasons why the criterion is the optimized performance level. First, some conventional performance levels aren't adequate for frugal innovations. A good example is the car horns in Indian cars. Since they are used excessively in India, they must withstand much greater stress than in developed markets and even more strain than in emerging markets.

The second reason is that the required level must be met very precisely. If the performance level is too high, as it is with the premium Western construction equipment, costs are too high. As noted, frugal innovation's core objective is to reduce costs. If the performance level is too low, then the goals of delivering "high value," "maintaining quality," and "maximizing value to the customer" are not achieved [22,23].

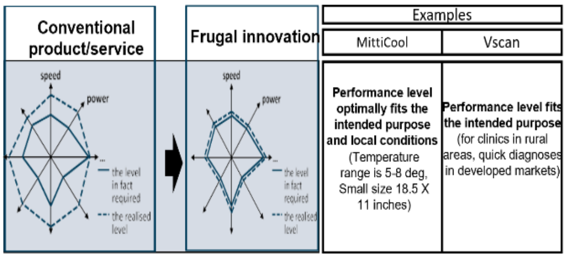

Fig 7. Optimized performance level

In short, a frugal innovation must meet the level of performance required for its practical purpose and local conditions compared to current solutions [22].

IV. CHARACTERISTICS TO BE CONSIDERED TO MAKE THE PROCESS FRUGAL.

This section introduces and discusses the characteristics, considering which the convention process can achieve frugality.

1. Minimal waste and high utilization of the resources.

The frugal process is often described as the required resources, both in terms of efficient utilization of resources and whether they avoid the use of specific resources altogether to become self-sustaining [8]. "Waste" in literature is understood as unused inputs, material, by-products, or environmental waste created in the standard engineering process [3]. The waste minimization methods are often discussed in procurement or production processes and are less prominent in discussion on distribution [15].

An example of this is how Hyundai India eliminated all sorts of costly aspects from their product development process, from passing these savings on to their customers and designing and developing vehicles from fewer materials, with more performance in less time [3].

2. Localized frugal process.

Frugal innovation is frequently determined by addressing the local market by adopting local means of innovation and as well as by localizing the value chain with a strong focus on local manufacturing, local suppliers, and raw materials acquisition and on local distribution channels [11].

3. Technology enabled

Simplicity and cost reduction are not only achieved by using low resources but rather through reconfiguration and redesigning the utilization of high-tech components. Value creation and capture are challenging as the production constraints and transaction constraints are limited at the BOP. These challenges can be overcome by technology [16].

For example, Saint Angelo achieved a successful C2B transformation by carrying out frugal innovation based on an internet strategy. Saint Angelo adopts an "internet plus" management mode to get through different links (e.g., supply, production, R&D, sales) to digitize its entire value chain and ultimately to realize high synergy with low waste [17].

4. Integrating local population

One of the prominent elements for frugal innovation is concentrating on integrating the excluded population into the economy, thus regarding the poor not only as potential consumers but also as producers and suppliers [18].

5. Iterative

Iterative processes for continuous improvement were noted as necessary, particularly in procurement [8]. Another factor for the faster-initiating process is applying a short-term approach like the "Trial and error method" rather than a long-term approach for project planning [19]. Frugal innovation encompasses the acts of numerous individuals, not only inventors but also producers, consumers, and intermediaries. It comes from the cumulative effect of applying the small-scale ideas over Long-term periods [20].

6. Simplifying process complexity

Many papers address the need to reduce the complexity of the innovation process to a frugal outcome [8,19]. It involves simplifying some processes and introducing and integrating technologies within the others, which is necessary for product development [7,8], and production [3,19]. “The approach is basically to reduce the length of the supply chain and carry out all steps autonomously, and thus we are competitive regarding manufacturing and overall costs” (Quotes manager of Industria Fox) [19].

7. Collaboration

Firms are often encouraged to carry out certain processes in collaboration with non-traditional stakeholders, such as non-government organizations and with local suppliers, for a successful value chain [7,8]. In addition, Collaboration with multiple stakeholders has also been dubbed as “Polycentric development.” Integration of the local population at the BOP is highly advisable due to the “social embeddedness” and unique insights that only they can provide [3]. In this regard, the Senior Manager of Hyundai Motor India Limited mentioned that “We have collaborations with more than 100 local Indian suppliers who manufacture critical vehicle components, modules and integrated systems for us. Alliancing with our suppliers and leveraging their expertise has enabled us to develop practical solutions for addressing some of the sturdy challenges we faced for innovating vehicles for the Indian market” [3].

8. Flexibility

Frugal processes are often designed to be quickly adaptable in order to ensure a great deal of flexibility [8]. “Innovation for process improvement is adaptive and able to expand and be scaled up, in both size and purpose- which magnifies the impact” [21].

9. Self-sustaining

Self-sustaining processes attempt to overcome resource constraints by designing processes that must be carried out with as few inputs as possible in the first place. For example, healthcare services should be carried out without seemingly compulsory resources, such as access to electricity, professional staff, or supplementary medical equipment, all of which could be lacking in severely resource-constrained environments [15].

V. TRADITIONAL SUPPLY CHAIN VS. FRUGAL SUPPLY CHAIN

1. Traditional Supply Chain

A traditional supply chain is defined as an integrated manufacturing process in which the Supplier provides raw materials or semi-finished goods to the manufacturer, who manufactures or assembles them into final products, and then sends the finished goods to the wholesaler, retailer, and finally to the customer [24].
The following are the stages of the supply chain:

- Manufacturers
- Wholesalers/distributors
- Retailers
- Customers
- Component/raw material suppliers.

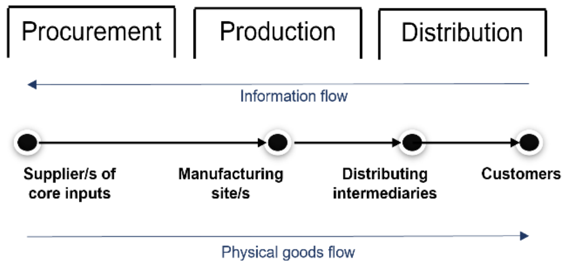

Fig 8. Traditional supply chain

2. Frugality at the Supply-Chain Level

The outputs of one supply chain stage become the inputs for the next. The way firms use to overcome constraints at one point of the supply chain is inextricably linked to their strategy at other stages.
We describe three models of frugal supply chains that companies might use to achieve frugality at the supply chain level, depending on their primary goal [8].
1) Postponing Decentralization (Archetype I): The first archetype was commonly used by businesses with the goal of increasing people’s access to affordable items. To attain reduced manufacturing costs per unit, companies frequently create a supply-chain structure that tries to rely on traditional economies of scale. They save their money to establish a powerful and decentralized distribution network with the goal of reaching a large number of potential customers (see fig 9) [8].

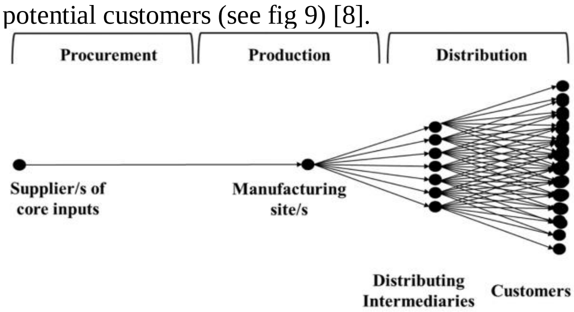

Fig 9. Postponing decentralization [8].

Most of these price points are attained through buyer-supplier interactions that resemble more traditional methods. For most cases, assembly is done in a factory in the country where the major components are sourced and then shipped into the target market's country via bulk shipments. Unlike procurement and production, which are both generally centralized, these distribution methods are extremely decentralized and focused on moving products down the supply chain and to the final consumer [8].

2) Balancing Investment Costs and Productivity (Archetype II): This second frugal supply-chain type was commonly used by companies that wanted to promote empowerment. Companies with a mission like this are less interested in building their supply chain to save money through economies-of-scale benefits like global sourcing or nonlocal production, which are common in Archetype I. These businesses must strike a careful balance between spending their capital in growing local talents and reaping the benefits of increased production while still fulfilling their objective of local empowerment (see fig 10) [8].

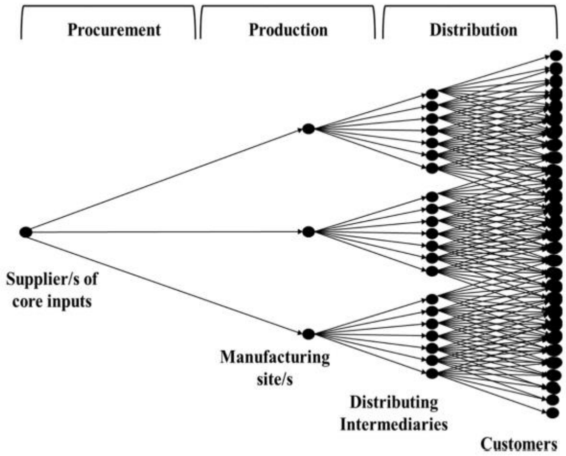

Fig 10. Balancing Costs and Productivity [8].

Raw materials for the products are typically grown by the company in a central area or purchased from a few suppliers in close proximity to the firm. This "decommoditization" of suppliers improves the firm's empowering purpose while ensuring the quality of inputs and the efficient use and reuse of limited resources across the supply chain. Firms of this archetype aim to build enough manufacturing capacity locally in order to be able to capitalize on economies of scale. However, in order to build such capacities at significantly fewer investment costs, they often rely on labor-intensive and simplified manufacturing. Simplifying the process also allows firms to employ individuals who would be challenging to hire otherwise in a non-simplified process. Firms have a high level of control over their production processes because manufacturing is done locally. Some businesses use this control as an opportunity to develop innovative solutions for further lowering end price points [8].

3) Hyperlocalization (Archetype II): Firms that want to provide customers with greener alternatives to existing products usually adopt the last approach. Companies with this objective do not minimize costs through economies of scale at any point in their supply chain [8].

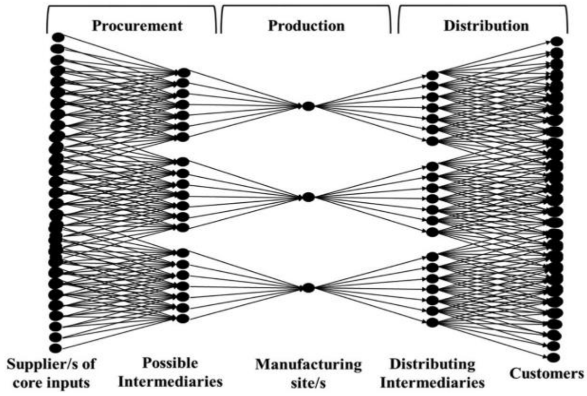

Fig 11. Hyperlocalization [8].

Instead, they want to build a hyperdecentralized local-to-local network that focuses on reducing logistics markups and transportation expenses. Obtaining activities focus on lowering procurement costs by sourcing waste products or growing the company's own raw materials, with a strong emphasis on procedures that minimize environmental damage and use fewer resources (such as water). In contrast to the preceding two patterns, sourcing is usually done through an extensive, decentralized network of micro suppliers. Individuals or households from multiple areas are frequently involved. Firms often implement technology-enabled processes to ensure maximum efficiency in resource allocation and utilization of this vast decentralized network [8].

VI. CONCLUSION

Despite being cheaper, more functional, or focused on basic needs, frugal products can still meet customers' needs. The first conceptualization of frugal processes addresses the development of frugal products. The second conceptualization emphasizes addressing all supply chain stages, not just the product development process. Lastly, frugal processes can be viewed as an outcome or the innovation itself, rather the means of achieving it. We identified the three primary criteria for frugal innovation and the key characteristics that enable the conventional processes to achieve frugality. The frugal process, as portrayed has the following 9 key characteristics.

1) Minimal waste creation

2) Localized

3) Technology enabled

4) Integrating the local population

5) Iterative

6) Simplified process complexity

7) Collaboration

8) flexible and easily adaptable

9) self-sustaining

We discussed the three possible archetypes for achieving frugality in a supply chain and which archetype is suitable for firms with different primary goals.

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Frugal Engineering and how does it change the life cycle of technical systems

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***Abstract*— Frugal Innovation and its impact on the Life cycle on technical systems are the two concepts being deliberated among the policymakers, engineers, researchers of the developing and developed countries alike. The current work provides a rundown of the approaches to the frugal innovation adopted in the Manufacturing sectors, Defence sectors, Business models, etc., and the life cycle assessment of the whole process. The current work establishes the conceptual framework based on the literature reviews and case studies analysis. Frugal innovation undoubtedly impacts the life cycle of the technical systems and in many cases validates the improvement.**

The result of our findings shows that the impact of the Life cycle of systems through the Frugal approach would concern the socio-economic, geographic context of emerging economies. Rapid technological development, adopting different supply chain strategies, and the efforts to generate inclusivity to empower the communities to achieve the core functionalities are the outcome of Frugal innovation considering a Resource-constraint environment.

Key Words: Frugal Innovation, Bottom of Pyramid, Constraint-Based Thinking, Life cycle Assessment, Reusability, Modular Approach, Microentrepreneurship.

I. INTRODUCTION

The topic of innovation has typically been the realm of emerged countries, like the United States, Japan, and the United Kingdom. However, emerging countries are quickly catching up, not out of greed, but out of need. Emerging countries are nations with low living standards, underdeveloped industrial base, and low Human Development Index relative to other countries.[1]

Frugality, derived from the Latin word frugal is, is a concept that has been existing in society for several years under different forms (e.g., 'DIY' in the US, 'Jugaad' in India, 'Zizhu' in China, and 'jua kali' in Africa). Businesses realized the special competencies of the local population in innovating cost-effective products, quickly and in a resource-constrained environment which was later referred to as "Frugal Engineering". Resource constraints such as less developed infrastructure, institutional voids, illiteracy, and low purchasing power were identified as major driving factors for these innovations. Other constraint-based innovations such as inclusive innovation, grassroots innovation, Gandhian innovation, catalytic innovation, indigenous innovation, resource-constrained innovations, and reverse innovations are already introduced in the same context. However, Research scholars are increasingly using a common term of 'frugal innovation' to refer to all these innovations. Research acknowledges frugal innovation as a multi-dimensional phenomenon with three primary dimensions—Product, process, and context. Product dimension includes the characteristics of being simple, robust, and focuses on the core and required functionalities. The process includes a bottom-up creative process to respond to challenges, localized development, and scaling options. And the context dimension includes the affordability aspect, resourcefulness, and radical or transformative implications.[2]

Over the years, frugal innovation has come a long way from the initial focus on Bottom of the pyramid (BOP) customers in emerging markets to be explored as a concept in combating challenges at a global level. Environmental and demographic (e.g., aging population) as well as socio-economic changes (e.g., growing cross-border migrations) are being identified as sources of this contextual shift beyond Bottom of Pyramid (BOP) markets. This study attempts to showcase the impact of frugal engineering on the lifecycle of the technical system. The rest of this study is organized as follows. Following this introduction to frugal engineering, there is the current state of the art and then exhibiting the impact of frugal engineering on the life-cycle of a system by classifying frugal engineering in two directions,

a) Based on the approach to achieve frugal engineered products and,
b) Based on the geographical location where frugalism is to be achieved.

Lastly, the paper closes with some limitations, conclusions, and references.

II. State Of The Art

When it comes to frugal innovation success or failure, the motivation for such marketplaces is not comparable. The market in which Frugal Innovation is created also influences its definition. Several studies were performed in the field of Frugal Innovation considering the criteria for significant cost reduction. To be effective in the success or failure of Frugal Innovation, optimized performance in combination with user-related aspects such as acceptance and prestige are useful. Frugal Innovation can be a tool for sustainable development, but it requires a collaborative effort, resources, and motivation from a variety of stakeholders, including private sector actors, governments, development agencies, and urban society.

Frugal Innovation aspects are removing unnecessary features, replacing expensive materials with available alternatives, paying attention to personal and societal demands, cultural problems, having skills, multi-skilled entrepreneurs, and paying respect to nature. Further research could determine compliance, participation, and limits on various tactics for local MNCs and enterprises, as well as international and local businesses. The importance of the government's Frugal Innovation in combating COVID 19 was emphasized. While certain governments have been successful in establishing and maintaining a Frugal Innovation culture, future research should look into how governments can embed the values and attitudes that facilitate Frugal Innovation in the long run. Business acumen, management reluctances, challenges in R&D, challenges in prototyping, currency fluctuations, smuggling, information and difficulty in SCM, lack of infrastructure, fear of competitors, low protection of intellectual property rights, cultural issues, and resource scarcity are the most significant barriers to Frugal Innovation. Like the use of value ratio (the ratio of worth divided by costs), a frugal value ratio is suggested in which, enablers and critical success factors are set as numerators and barriers are set as denominators. Each of the factors can be given a relative weight, and the components can then be multiplied by each other. The value of such a ratio can then be used to rank frugal innovation strategies or opportunities for new product/process development. This study lays the groundwork for prioritizing frugal innovation strategies or new product/process innovation options using multiple criteria decision making (MCDM).

Finally, the findings of this systematic literature analysis can be applied to organizations that aim to innovate in low-resource environments as well as the BOP. Additionally, the proposed approach can be employed by organizations that want to innovate while still protecting the environment. Researchers can utilize the findings to investigate and rank aspects in their local settings.[3]

III. Research Implication

After going through several papers for this research we decide to divide the outcome part into two sub-parts. Those two sub-parts are discussed in detail in the following section.

A. Based on a strategy used to achieve Frugal engineered products

In this section, we will analyze how the method used to achieve frugality determines a technical system's life cycle. The management, information technology, and organizational culture all influence this strategy. [4]. For example, in India's manufacturing department, cost reduction is achieved by integrating new and modern frugal engineering technologies in the manufacturing sector to boost precision, production rate, and assembly-line efficiency. The six key ideas briefly outlined below can explain the Indian manufacturing sector's frugal engineering efforts: Robustness, Portability, Leapfrog technology, Mega-scale production, Service ecosystem, and Disfeaturing. The frugal manufacturing strategy entails dismantling and reconstructing a cycle, which results in a simpler, more resilient, and easier-to-handle process and a more cost-effective final product.

Instead of academic literature in emerging countries, frugal engineering arose from the company's response to various restrictions. Frugal engineered products must be able to deal with a variety of infrastructural issues as well as be market compatible, and they must have a reasonable price for reasonable product performance. Frugal Engineering is a systematic technique that has compelled and inspired manufacturing industries all over the world to re-evaluate and re-strategize their processes. Frugal engineering breaks down the entire product engineering phase into its most fundamental mechanisms and then restores it in the most cost-effective manner possible. The challenge is to pick between product features and a cost-cutting decision. The entire strategy revolves around identifying consumer demands and meeting them through various methods. [5].

We researched Tata Nano which is one of India's most significant achievements in terms of frugal innovation. For the development of the car TATA management chose "concurrent engineering in real-time" for the development process, and applied the modular technique for car production. TATA motors filed 34 patents related to the technical systems of the car as a result of this strong feeling of frugality in the development process. But, even after achieving so much with frugality, the first model of Tata Nano had some safety flaws, causing customers to be upset and significantly impacting the product's life cycle [6]. A case study was conducted using two inexpensive passenger automobiles, the Tata Nano and the Renault Kwid. Because the chosen product was well-suited to users in the low and middle-income groups, these cars were picked to research the product based on the FIs' essential parameters. The traits linked with the Frugal innovation were presented to the participants, along with an explanation or description of the attributes. Users were given a questionnaire, and their replies were gathered based on their experience and perceptions of using the selected product. According to the findings, the TATA Nano excelled in terms of affordability, while the Renault Kwid excelled in terms of aesthetics, usability, functionality, and affordability. The passenger automobile case study helped establish what factors contributed to the design's frugality failure. Additional characteristics of frugality include functionality, beauty, robustness, performance, usability, and accessibility [7].

Another example of frugal engineering in India was discovered in a paper in which it was used in complex systems such as nuclear reactors. The difficulties faced during the early stages of nuclear development, when they lacked both material and technological resources, are discussed in the paper. While developing the second reactor of a two-unit pressurized heavy water reactor (PHWR) plant of Canadian design, India's nuclear program was cut off from worldwide nuclear supply networks, leaving it with the challenge of finishing a half-finished reactor after a nuclear test in 1974[8]. This lack of access to global resources necessitated reinvention or reverse-engineering, as the country lacked design knowledge and manufacturing capability for the equipment in question. As operators begin to recognize patterns of problems or read signals that are difficult to record or measure, rigorous product development and testing led to improvements in system performance (lower operating and maintenance costs, fewer mishaps, higher capacity factors). These iterations of continuous learning assisted designers in developing better sub-systems of the larger system, which in turn enhanced the life cycle and longevity of system components, resulting in superior versions of the original design. The distinction between technology transfer and technology absorption became clearer as the learning process progressed. Later in the 2000s, Indian and Canadian designers began to collaborate, and Canadian designers were taken aback by the designs and techniques used by Indian designers to create sub-systems that were simpler, more efficient, and durable, which they had previously believed would never work in a nuclear reactor. Finally, strong evidence opens up a new domain for frugal innovation, dubbed frugal reverse engineering, in which Indian designers were successful in developing a better nuclear reactor through frugality [8].

Many scholars have looked at the notion of frugal engineering by examining the finished product and its distinguishing qualities, as well as business models and ecosystems. However, just a few research have been conducted on how to build those cost-effective engineering products. This question is answered in the paper "How to design and create an innovative frugal product?"[9]. The process of developing user-friendly, appropriate, and economical solutions to resource-constrained situations is known as frugal product development. Because of institutional holes and scarcities in both the working and living environments, this strategy has its roots in emerging economies. The result, frugal innovation, is goods and services that tackle transitory and context-specific issues cost-effectively and strategically without compromising quality. This paper examines frugal innovation as a design development process and analyses a case study from Brazil to satisfy this need. The research contributes to frugal innovation by serving as a process guideline for the approach, allowing researchers to see how contextual demands and constraints, frugal criteria, and design process steps are configured and integrated to produce the final product. With the use of assessments based on trash picker equipment, the study also distinguishes between the conventional and frugal new product development processes.
Based on their findings in the paper, the researchers created the Adjusted Frugal Product Design Process Model, which may be used as a step-by-step guide to designing frugal innovation products. From a managerial standpoint, the study also contains four ideas for designing a frugal engineered product [9].

An organized technique for producing inexpensive inventions was presented in a paper-based on constraint-thinking. This one based on constraint-based thinking answers the topic of how to produce inexpensive innovation. The origins of frugal innovation can be found in resource-scarce emerging economies that face a variety of restrictions, including cheap costs, harsh conditions, and a lack of regulatory oversight. Constraints have a significant impact on the cost-effective product development process and end attributes such as robustness, portability, and user-friendliness. This research looks into how a constraint-based approach might be applied to the development of frugal products. The goal of this research is to provide a structured and iterative approach for identifying restrictions and specific product requirements and features. The study looks at two case studies of healthcare equipment to show how a constraint-based strategy can lead to successful frugal innovation. As demonstrated in this approach is made up of problem space and solution space, with four iterative steps. Context-specific tasks are referred to as constraints. They define a problem area for creativity and regulate the amount of creativity available as well as the number of alternative solutions to the initial problem. Constraints do not affect the development process directly, but rather alter the circumstances of normal flow. The researcher proposes a novel constraint-based thinking approach as a structured and iterative process for identifying constraints and mapping them to specific features and requirements that may directly or indirectly impact the development process for frugal innovation [10].

Next, we reviewed a paper on the life cycle assessment of a Solar Energy System Based on Reuse Components for Developing Countries as part of our research. The importance of electricity in rural areas was emphasized in this paper. Based on the frugal innovation concept, the reuse of discarded components in renewable energy systems has been suggested as a possibility for rural electrification in areas where renewable resources are abundant [11]. Rapid technical advancements, innovation, and customer expectations have resulted in a significant improvement in electronic equipment, resulting in a shorter electronic product life cycle and a rise in worldwide electrical and electronic waste (E-waste). The goal of this study is to assess the life cycle of reused system components as well as their environmental effects. The paper focuses on the technical application of reusability for a Renewable Energy System that includes a solar element made up of solar photovoltaic (PV) panels, modified Power Supply Units (PSUs), and an energy storage system made up of old lead-acid automobile batteries. The methodological framework of life cycle assessment (LCA) has been chosen to assess and compare the life cycles of conventional and repurposed systems. Due to aging and improper use, the efficiency of the modified power supply unit and modified UPS in the reuse case is estimated to be 10% lower, and the efficiency of reused solar panels and automobile batteries is estimated to be 10%-30% lower than that of younger systems. In comparison, through frugal innovation, the reused system was able to provide energy at a lower cost and extend the system's life expectancy (End of life). The absence of battery manufacturing, on the other hand, resulted in a 40 percent reduction in environmental impact [11].

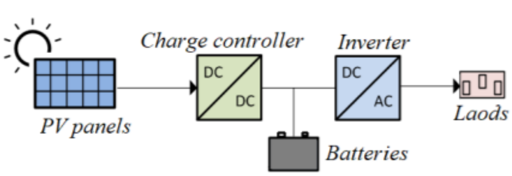

Fig 1. Solar PV system using a conventional set-up [11]

Fig 2. Solar PV system containing second life components [11]

TABLE I. COMPONENT SERVICE AND REPLACEMENT TIME [11]

		Life cycles	Lifetime (years)	Number of replacement
Conventional system	Solar panel	-	20	1
	Solar Battery	2000 cycles	5.48	3.65
	Inverter/ Charge controller	-	7	2.86
Reuse system	Solar panel	-	20	1
	Car Battery	500 cycles	1.37	14.6
	PSUs/UPSs	-	5	4
	Microcontroller (Arduino)		10	2

Advanced Frugal Innovation (AFI) is a new class of frugal innovation that uses scientific and technological developments to reduce resource use, according to the publication "Advances in Science and Technology Through Frugality."[12] Innovations for sustainable development have been portrayed as a win-win situation in the face of environmental and economic turmoil. In this context, cost-effective science and technology (S&T)-based innovations can help to preserve material resources and hence contribute to long-term development. During the previous decade, the rise of frugal innovation has been viewed as a grassroots phenomenon, where a scarcity of resources encourages frugality in innovation. As a result, grassroots inventions give a wealth of information on how to maximize limited resources for the benefit of individuals at the bottom of the economic pyramid. Several breakthroughs originating from advances in science and technology, ranging from autos to healthcare, astronomy, and particle physics, have shown frugality in recent years. Rainfall sensors and plasma-colliders are examples of research that led to the development of advanced turbochargers that give more power and torque from a smaller, and thus less expensive, four-cylinder engine while simultaneously reducing fuel and pollutant emissions. At a low cost, smart-mobile-phone has been utilized to screen for communicable and non-communicable diseases like tuberculosis (Martin and Upham 2015) and intestinal worms.Frugality is a force for good in terms of sustainable development, and it may be found in a range of innovative applications.[12].

The first step toward truly inexpensive innovation, according to "A Framework for the Improvement of Frugal Design Practices,"[7] is to identify important features. The seven key qualities of frugal innovation (RII) are identified in this study using 80/20 analysis and the Relative Importance Index. A case study was undertaken to analyze the characteristics of FI, which assisted in establishing whether the experiment's identified characteristics are true to their purpose of building a frugal innovation. Seven important features for frugal innovation design are found using a cumulative frequency distribution analysis (functionality, usability, performance, affordability, accessibility, aesthetics, and robustness). A descriptive-statistical method called the Relative Relevance Index (RII) is utilized to determine relative importance for each of the main traits identified individually [7].

Fig 3. The method for determining the attributes consists of three steps [7]

The current economical design approach is focused on cost savings, usefulness, and long-term performance. Although these are crucial features for producing products in terms of cost, productivity designers must also consider aesthetics early in the design process, as aesthetics play an important role in boosting product reachability and scalability [7].

Now coming to the case of industries that set up production plants to serve a variety of markets, a complete overhaul of the design and installation of Production systems (PS) is sometimes required to comply with the regional markets and their requirements. Researchers looked at the system's configuration options. The modularity-based design employs knowledge-based mapping of workstations that meet site requirements, cost structure, worker ergonomics, energy standards, and other criteria [13].

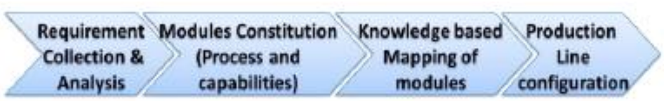

Fig 4. Global method of modular PS design [13]

The use case of Comau, a supplier of industrial automation, for a power train manufacturing line is investigated. The following structure defines the modules in the workstation: Motion equipment, process equipment, and control equipment are all examples of motion equipment. Fig 7.

shows how motion equipment (green) is used with process equipment (blue) to complete a specific task. Gripper, for example, is used to install the windscreen on a vehicle. The control equipment, together with the workstation's software, includes electric, pneumatic, and fluidic connections [13].

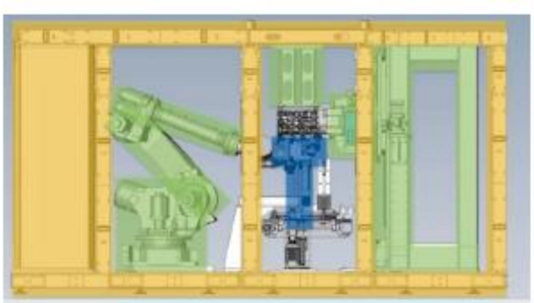

Fig 5. Equipment modularity to the workstation [13]

Depending on the power, space, and manufacturing requirements, the motion and process equipment are evaluated for compatibility with other goods for re-use. This concept is supported by an integrated 3D visualization assistance tool that validates the solution and saves time and money during the early stages of system design [13].

So, the summarize the outcome of this part we can say that the strategies used to develop a frugal product determines the technical life cycle.

B. Based on the geographical location where frugalism is to be achieved.

In this section, we will study how the technical life cycle is affected according to the region of development.

Emerging markets, such as Asia and Africa, provide an ideal ground for developing and testing revolutionary products that are inexpensive, good enough, and low-cost to meet customers' basic demands. The resources available in a given region have an impact on the life cycle of technical systems. Moreover, the core causes of frugality's adoption as a societal norm may vary depending on the social setting, particularly between developing and developed countries. It is about cost considerations for Indians, but it is about environmental concerns for Germans, which might be described as "frugality by choice." But, to secure German companies' long-term competitiveness in emerging economies' fast-growing, unsaturated sectors, Frugal innovations are essential. Engineers in German organizations are unduly reliant on high-tech-driven, complexity-embracing innovation paths, which has been identified as a key impediment to the application of frugality. There was also universal agreement that inexpensive innovations are required to ensure German company’s long-term competitiveness in emerging economies' fast-growing, unsaturated markets. To meet the needs of evolving market segments, the expert interviewees proposed that German companies explore introducing frugal solutions in emerging markets as well as the German market [14].

Given the constraints in both emerging and developed countries, the paper "How might 'frugal innovation' be conceived" implies that Frugal innovation has reawakened attention. The study presents two types of data: historical data from now-developed markets during their development and current data from emerging economies as they seek to develop. The purpose of the historical view is to show that a cost-effectively innovative method is not a novel concept. Inventors and entrepreneurs like Benjamin Franklin used limited resources to create frugal solutions for everyday problems like the Franklin stove, lightning rod, bifocals, and carriage odometer in eighteenth-century America (Franklin 2008). During World War II, the CC41 scheme in the United Kingdom, DIY (do-it-yourself) in the United States, and System D in France all had resource limits. However, we believe that the necessity of frugal innovation is not limited to developing countries, but is gaining traction globally as a result of global recession and austerity concerns. Emerging markets are evolving in ways that are substantially different from how the industrialized world did. Motorbikes and rickshaws are the most common modes of transportation in India; formerly, telecoms were in their infancy and only available to the elite. Emerging markets now have a greater mobile phone penetration rate than many developed nations. While emerging markets have resource constraints in some ways, they can also build and utilize global technologies to leapfrog over and beyond established countries' legacy and aging technical systems [15]. In wealthy countries, providing basic services to all inhabitants is getting increasingly difficult. Global financial liquidity is low, government spending is being slashed, public debt is at an all-time high, natural resources are scarce and in high demand, prices are rising, and consumers are cutting down on their spending. When sales are down owing to the recession or earnings are constrained due to greater competition, businesses adopt frugality. Part of the motivation for providing low-cost creative services is to help others, but there are also unmet commercial needs.

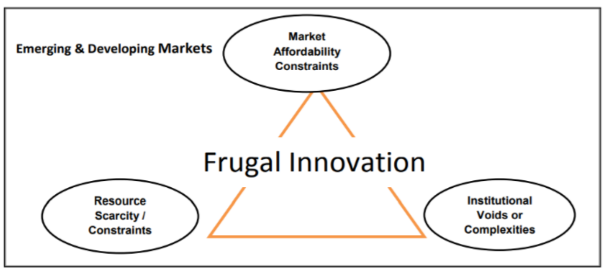

Fig 6. Conceptual model of Frugal innovation in emerging markets [15]

The study proposes a value chain model that indicates what frugal innovation could mean to both the upstream supplier and the downstream consumer. To meet the demands of underserved consumers in constrained environments, a frugal solution must be designed, produced, delivered, and maintained from the firm's or supplier's perspective. A frugal solution may extend beyond the cost of the solution to include operations and disposal costs. To function to its full potential, a product or service requires complementary solutions, resources, and infrastructure. Frugality may thus imply not only lowering the product's cost but also how it is built to perform in a resource-constrained environment, using fewer resources and against complex or ineffective institutions [15]

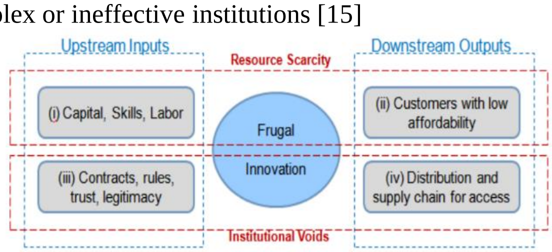

Fig 7. Value Chain Model based on Contextual Environment [15]

One research [16] examines the cases of companies that have achieved global success through reverse innovation. All of these businesses took the resource constraint-based thinking approach, with those at the "Bottom of the Pyramid" as their target clients. The article examines four Asian businesses, one of which is situated in India and the other three in China. Companies intending to operate in this new industry, according to the report, must be adaptable to opportunities originating from consumer market constraints. Furthermore, they must be adaptable enough to acquire new capabilities to match the aggressive price/performance ratios demanded by consumers. A corporation must be well-prepared for a long-term R&D effort to successfully adopt disruptive innovation in emerging markets. To successfully deploy disruptive innovation in emerging markets, a company must be well-prepared for a long-term R&D effort and manage the intellectual property to prevent imitators. This method may lead to the successful development of businesses; nevertheless, it necessitates vision, originality, and flexibility in the product engineering phase to build items that match desired market needs at a reasonable price [16].

In one paper, researchers looked at frugal innovation and its reception in Brazil by looking at six Brazilian firm instances (three multinational corporations and three small and medium-sized businesses) [17]. The findings from Asian markets were compared to factors such as cost-effective product development, product attributes, and commercialization tactics. Six cases were investigated in this study, spanning various industry verticals such as energy, automotive, cosmetics, and household appliances, using semi-structured interviews lasting 50 to 90 minutes, as this method provided comprehensive data to derive underlying structures, relationships, and dynamics of both the company and its product Sampling was done on purpose, by the company's demand that it develops and create its goods in Brazil and for the Brazilian market [17]. Four of the six enterprises create their products from the ground up, while the other two MNCs specialize in product customization and adaption for the Brazilian market. The sampling results challenge the general pattern of low cost, fewer features, and cost-effectiveness in frugal innovation by proposing a two-fold approach to the cost criterion that distinguishes between customer and company perspectives and focuses on distinctive product features, branding, and value-based pricing, all of which are critical for successful frugal innovation in the Brazilian market [17].

In emerging nations, the framework of the process model works on Scaling through Replication which develops the network of microentrepreneurs through training in the community. This process model does not halt the production during the uncertain environment in which the developing countries operate where power outrage is very common and government regulations and policies are not in place. A good balance of frugality between labour-intensive processes and sturdy and partially automated assembly lines enables the process to be independent [18]. The decentralized approach of microentrepreneurs reduces the workload of logistics and transportation planning required for the distribution of products. Wana Energy, founded in Uganda, is a company that uses frugality in its interactions. They give the people cookstoves and gas cylinders because agricultural products are their main source of revenue. This organization offers a variety of transaction options for individual customers, depending on their preferences. They can pay with what they create or use mobile to "pay as you go." This adaptability boosts inclusivity and expands the distribution route [18]. The company has created a technique in which gas cylinders are also connected with remote monitoring, which warns the company when the tank is going low and allows prompt contact with microentrepreneurs and franchises to distribute to the last miles of rural areas [18].

In another study, it was discovered that when locally produced raw material may replace the existing material, procurement time is greatly decreased. A goodly is a Taiwanese company that makes toothbrushes out of Moso bamboo. [19]. The fastest-growing bamboo plant has been discovered to be the greatest choice for replacing the harmful single use of plastic in toothbrushes, ensuring the product's recoverability. However, there are other instances where resources are scarce and businesses must make the best of what they have. This case study is obvious in West Africa, where technological progress is limited to second-hand electronic products imported from European countries. WoeLabs is a community hub that manufactures 3D printers from recyclable e-waste [19].

As in emerging nations investment is low. For frugal innovation, people are dependent on government policies. For example, Multiple refusals to the early induction of the initial version of the Akash missile by the Indian Army. They demanded optimum performance and zero error procurement which would have called out for importing technology from abroad. This led to the delay in the procurement and deployment of a system within a given timeframe. Ultimately, after facing significant delays from govt policies and foreign agencies, they agreed to induct the incremental approach to develop the system indigenously and improve it further through a series of user trials and feedback which would have saved them a significant amount of time. [20] Eventually, it proved to be useful as during the test of the Akash missile, the engineers accidentally identified the ground radar later named (Rajendra Radar) which could detect the nearby artillery shells being fired. This was later adapted for inclusion in Weapon locating Radars which averted the import of American radars which was costing time overruns. [20]. It is crucial for procurement policymakers to make necessary changes and appreciate the innovation-led development of systems in-house through learning and technological up-gradation [20].

Frugal innovation is usually invented and diffused in developing countries, where resources are strictly limited, consumers have low purchasing power, and there is insufficient infrastructure. Scholars have shown increasing interest in frugal innovations in recent years as these innovations can satisfy the demands of the majority of the population living in developing countries, develop conceptual frameworks of frugal innovation, and conduct case studies. One research that studies Frugal innovation in emerging markets, states that Frugal innovation promotes sustainability, which means not only financial prosperity to the company but has socio-environment benefits as well. This research studies 94 cases from emerging and developed countries and compares them. Focusing on emerging markets it concludes that innovation in these regions starts at the grassroots level. Innovators are mostly internally motivated with negligible external support in terms of capital. The difference between the approach of grassroots innovations and mainstream frugal products is that at the grassroots level innovations occur from scratch, whereas in the mainstream market companies look to replace parts with cheaper material in the name of frugal engineering. Research and development at the grassroots level also take a lot of time than in traditional methods, which increases the product development life. The life cycle of the technical systems is extended with help of online markets [4].

To summarize this section, we can say that the technical life cycle changes as the region of innovation changes. This is due to various policies, capital, resources, need in regional markets, and the approach of innovators.

IV. Conclusion

This study aims to investigate and analyze the impact of frugal innovation on the Life cycle of the technician systems. For this purpose, we conducted a literature review to examine the role of frugality in different fields associated with life cycle assessment. There are several limitations to this research. First, most literature on frugal innovation is concerned with establishing criteria to define the topic. Second, so far, the majority of the research papers are concerned with the socio-economic context of emerging economies. Third, lack of research papers available on life cycle assessment as frugal innovation papers concerned with the Engineering field mainly focus on product design and development, features and technology, cost reduction, and effectiveness.

In this literature survey, we have referred to frugal innovation research papers from the field of automotive, cosmetic, manufacturing, household appliance, healthcare, defense, and energy and found frugality can be interpreted as both innovation and reverse engineering. The life cycle of the systems through frugality has a twofold approach

a) Low cost, defeatured products will have a short life cycle as these products are developed by keeping emerging economic countries (bottom of the pyramid) in mind

b) Reusability and reverse engineering of complex technical systems through frugal innovation aims to achieve long-lasting products (nuclear reactor is an example of the complex technical system mentioned in the paper). So, the life cycle of the system completely depends on factors like geographical location, target customers, cost, features, technology, size of the product, usability, and many more contexts. In short, Frugal innovation alone cannot guarantee the development of affordable and quality products with a long-life cycle because a successful product involves a fine balance of many factors.

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FRUGAL ENGINEERING

IMPACT OF FRUGAL ENGINEERING ON ENGINEERING PRACTICES

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***Abstract*—Scholars, practitioners, and politicians are increasingly interested in frugal engineering because of its potential to provide low-income clients with inexpensive solutions. As a relatively new notion, it has been investigated from several angles. We are familiar with the concept's good aspects, but its negative aspects have yet to be examined. To explore this site and gain a holistic view, we will study the effect of frugal engineering on different engineering practices.**

***Index Terms*—Frugal, frugal engineering, innovation, low cost, constraint based innovation**

I. Introduction

The implementation of ideas in the form of products or services is referred to as innovation. Companies are increasingly concentrating their efforts on offering solutions for low-income customers. Frugal innovations mainly originated in the context of emerging markets and because of their vast market size, expanding needs, and copious supply of R&D expertise, emerging markets have become new technological centers of gravity. The idea is to provide products and services that met the specific demands and expectations of these markets while remaining affordable to non-affluent clients [1]. Frugality, which comes from the Latin word frugalis, is a notion that has existed in many forms throughout society for many years (e.g., DIY in the US, Jugaad in India, Zizhu in China, Jua kali in Africa and Systeme d in France).

Meanwhile, cost-effective inventions have made their way into established markets as well. But, exactly, what does frugal innovation entail? What sets frugal innovation apart from other forms of innovation? Definitions of frugal innovation are frequently provided in publications in the area, and they rely on the possible aspects of frugal innovation (for instance, significantly lower costs, ease of use, limited features, and low impact on the environment). By far the most referenced and recognised definition is that given by [2], where frugal innovations is described as ”good-enough” and cheap goods or services that meet the demands of the bottom-of-the-pyramid population.

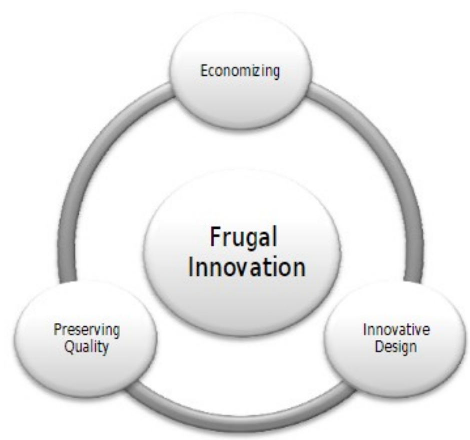

Fig. 1. The three driving forces of the concept of frugal innovation

The key motivating reasons for these innovations were recognized as resource restrictions such as underdeveloped infrastructure, institutional gaps, illiteracy, and poor buying power. Other articles [3] attempt to establish frameworks to identify frugal innovations from concepts like low-cost innovation, good-enough invention, Jugaad innovation, frugal engineering, constraint-based innovation, Gandhian innovation, or reverse innovation. However, there are currently no defined criteria for identifying frugal innovation.

We try to study the following issue with this paper: what is frugal engineering? and what are the impacts of frugal innovation on engineering practises? To begin, we did a literature study to determine the characteristics and traits of frugal innovation. Secondly, we study the impact of the effects of frugal engineering on different segments of engineering. This paper is structured as follows, in the next section, we provide an overview of the past and present scenarios of frugal engineering. We then explain the methodology adopted for our studies. On the basis of our literature review and findings, in the ”Conclusion” section, we deduce the criteria of frugal innovation and its impact on the engineering field.

II. Literature Review

Innovation has been a highly researched topic in literature for past few years. It is essential for both economic growth and competitive advantage in businesses and countries [4]. The high growth rates, large market size, and large workforce in developing nations have assured that enough scholarly attention has been paid to ”winning in emerging markets” through region-specific methods [5]. Researchers have looked at these nations at every stage of their development, from the first ’Exnovation’ [6] to the current technology transfer from emerging to industrialized economies [7].

To explain this occurrence, many theories such as ”reverse innovations,” ”disruptive innovations,” ”cost innovations,” ”frugal innovations,” and ”jugaad” have been offered [8]. All of these ideas are based on the same notion of rethinking and building goods and processes from the ground up at a low cost while meeting regional requirements. Consumers in the West are becoming more interested in products that were designed expressly for emerging markets [9]. For the sake of this research, we'll focus on only two of these ideas: frugal and reverse innovations.

Frugal innovations are defined as ”good-enough, inexpensive goods that suit the demands of resource-constrained consumers,” according to [8]. Frugal goods with minimal resources provide significant cost benefits over existing alternatives, and are significantly simpler and less expensive with fewer features. Frugal inventions are often designed for domestic use and are not intended for global dissemination. Reverse innovation, on the other hand, uses multinational innovation teams to create market-oriented goods in emerging economies that are intended to be marketed globally from the start [10]. As a result, the distinction between frugal and reverse innovation is critical, as reverse innovation is becoming a critical skill for multinational corporations.

Multinational corporations from all around the world are interested in the potential mass markets at this so-called ”bottom of the pyramid [BOP]” [11]. Developing low-cost products for BOP markets provides these enterprises with a huge potential to develop a solid presence in emerging economies [1]. The initial goal of western MNCs was to profit from low-cost manufacturing. Those same firms, on the other hand, have built local operations, are actively spending in R&D, and are forming long-term alliances in growing markets [12]. These initiatives are partly motivated by the difficulties that Western businesses face. Homegrown enterprises compete on strong price/performance ratios demanded by emerging settings, putting Western corporations' market share at risk. Because of their expertise in their home markets, these western corporations are sometimes unprepared for and unsympathetic to certain of the demands arising from resource limits in these countries.

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This report will describe the findings of an exhaustive literature study in the following sections.

III. Research Methodology

First, it's worth considering if the premises for employing inventive items in frugal innovation projects differ from those for use in other engineering practices. So far, the method for locating relevant products in frugal innovation projects has remained a mystery. It was discovered as a result of previous studies on thrifty innovations, which included interviews with concerned executives from different companies. A methodical search of our own knowledge base for industries is chosen. Other empirical research show that at the beginning end of innovation, only a few businesses use systematic search and idea generation approaches. The majority of the time, creative approaches are only used for impromptu brainstorming sessions. Due to the unique needs of frugal innovations, it is to be expected that, in comparison to ”regular” innovation projects, frugal innovation development teams would be more open to outside expertise and recognize the importance of methodical search methods. The industries were chosen after extensive brainstorming among the team, with a focus on the extent of frugal engineering penetration, and we chose the most penetrated disciplines. Because the phenomenon of frugality is still in its early stages and the study is exploratory, the systematic research study approach was used. The influence of engineering techniques in three disciplines of successful frugal inventions is the subject of this research [10].

IV. Effects On Engineering Practices

Frugal innovation is gaining hold throughout the world, not just in emerging countries, but also in developed economies. However, depending on the social setting, the basic causes of frugality's adoption as a cultural norm may differ. According to the experts, frugal products and services should focus on the essential demands of customers and eliminate needless complexity while maintaining high-quality standards. In this part, we highlight a few cross-sector examples of cost-effective products and services, which includes the healthcare industry, Automobile and Aerospace.

A. Healthcare industry

1) Frugal Innovation in the medical speciality: The overall frugal innovations target a wide range of specialities in the medical speciality of frugal innovation (European Parliament and Council, 2005): allergy and immunology, anaesthesiology, audiology, cardiology, endocrinology, gastroenterology, general practice, gynaecology, medical oncology, neonatology, ophthalmology, orthopaedics, otolaryngology, paediatric pulmonology and radiology "Fig. 2" [14].

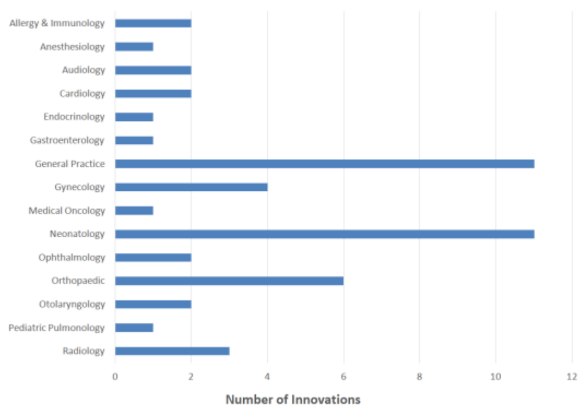

Fig. 2. Number of innovations by medical speciality [4]

With 11 innovations each, neonatology and general practice are the two most common specialities, which may be influenced by financing opportunities from big awarding agencies and non-profit organizations. The Tata Swach water purifier, a low-cost thermometer (from Leiden University, TU Delft, and Erasmus University), and a Philips portable ventilator (compact size, ease of use, and cheap cost) are all examples of innovations for general practice. Prosthetics like the Jaipur foot, a rubber-based artificial limb, and Cyborg Beast, a 3D printed hand prosthesis, are among the many advances in the area of orthopaedics.

2) Understanding the Customer for achieving business in medical speciality: Calculated trade-offs made during the product planning stage serve the dual purposes of keeping costs low while boosting the overall functionality and usability for the consumer. If planners want to gain a thorough grasp of how a product fits (or doesn't fit) into customers' lives, they must pay close attention and carefully observe those trade-offs.

A modest medical equipment business in China, Zhongxing Medical, produced an X-ray machine that costs one-twentieth of the price of standard X-ray machines built by Western corporations [15]. Rather than designing a machine that could do the full spectrum of complex scans found in Western hospitals, the business concentrated on a system that could only perform the most basic chest scans, which account for the vast majority of scans. Zhongxing has acquired roughly half of the Chinese X-ray industry by recognizing the core needs of its target hospitals — clinics that can't afford a normally priced X-ray equipment but yet want to serve the majority of patients.

3) Frugal Products Expectations in Medical Industry: The requirements of actors with reduced buying power must be addressed via frugal innovations. Frugal innovations aren't only a downgrade of current technology due to changes in requirements and preferences [15].

- **Reduced overall cost of ownership:-** A significant success element for the frugal inventions is not simply the price point at the moment of purchase. Rather, the low expenses of consumption, maintenance, and repair from purchase through disposal result in a much lower total cost of ownership.
- **Robustness:-** Customers in emerging nations' rural and semi-urban areas are frequently targeted for frugal technologies. The items must be able to deal with a variety of infrastructure issues, including voltage fluctuations, power outages, and other issues. Planned obsolescence practices, which aim to purposefully shorten a product's lifespan while lowering the related expenses for the consumer, are incompatible with frugal innovation.
- **User-friendliness:-** Companies cannot assume that their customers have a high level of knowledge with their products. As a result, frugal items must be simple to use and error-free.
- **Economies of Scale:-** Finally, the necessity for considerable cost reductions, as well as the tight profit margins nearly always associated with low-cost goods, need access to large volumes of business to lower research and manufacturing unit costs.

4) Instances of Frugal achievement in the medical speciality:

- **Multix Select DR - Siemens :-** Another SMART product is the Multix Select DR machine [6], a digital X-Ray machine that again demonstrates the reverse innovation notion associated with these economical technologies. This product was created not just for emerging markets, but also for worldwide markets. One of the most popular medical diagnostic procedures is an X-ray examination. An X-Ray examination is performed on about 90% of all hospitalized patients. For this diagnostic modality, emerging markets are increasing at about three times the rate of established economies. Despite this, X-rays have not penetrated widely, with about 4.5 billion people without access to them today.
  The Multix Select DR, a new digital X-ray system from Siemens, is an entry-level system that allows for cost-effective X-ray access. Multix Select DR is attractive to small and medium-sized hospitals in newly industrializing nations, as well as tiny hospitals and physician's clinics

in industrialized countries because it costs around a third less than equivalent Siemens predecessor products. This system costs around 30% less than Siemens' present high-end offerings, yet it meets most of the quality criteria in the western world. This device is also utilized as a backup machine in the Western world. Siemens also decreased the system's dosage needs by half, making it safer for patients and clinicians.

- **Fetal Heart rate monitor - Siemens:-** The Siemens Fetal Heart Rate Monitor (FHM) [16] is a low-cost invention created specifically for the Indian market. This product was not previously available in the Siemens worldwide catalogue, and it was created specifically for the Indian market's demands. Siemens' India research centre created the Fetal Heart Rate Monitor to meet the demands of the Indian rural market. The FHM is a gadget that can track the heart rate of fetuses while they are still in the womb. The Siemens FHM employs specific acoustic microphones instead of ultrasound technology, which can cost several thousand dollars in the high-end market sector. Despite the fact that the idea was originated and developed into a product at Siemens' Indian research centre, it was a worldwide effort including research teams from India, Germany, and the United States. Medical technologies that are both reliable and affordable, such as the Fetal Heart Rate Monitor, can assist improve the health care of individuals in rural regions and have a lot of promise.

B. Automobile Industry

Frugal engineering is more than just "cheap" engineering to increase profits through supplier negotiations. Rather, it's a philosophy that breathes new life into the idea of product creation. The goal of frugal innovation is to eliminate superfluous expenditures during the design process. Reference [17] discusses the growth of the concept of 'frugal innovation' in India is examined via the instance of Tata Nano. After Tata Motor's invention of the $2000 automobile, the world saw India's full potential in 'frugal innovation,' making it one of the most talked-about and admired examples of frugal innovation of the decade. Tata Nano, which claimed to pave the path for cost-effective engineering in the Indian car industry, went on to become one of the most notable breakthroughs. Tata Nano is one of the most well-known firms in the world for its frugal innovation. We have two approaches to study about Tata Nano's engineering concept: strategic and technical.

- **Strategic:-** The concept was to create an automobile for middle-class families that could ultimately replace two-wheelers on the market. The development approach required almost four years to complete before production could commence. A design chief, engineers, a production team, and graduate trainees were assembled into a team. A varied team was formed with the goal of generating distinctive and original ideas. Instead of only supplying technical requirements, the Nano team began to apply the concept of "concurrent engineering in real-time" by directly incorporating component suppliers in the early phases of product development. Suppliers were urged to examine the present work and offer their own practical suggestions that may help to create a more thrifty mindset. For example, Bosch of Germany collaborated with Tata Motors to develop a new engine management system (EMS). Denso's unique windshield wiper system only used one wiper rather than two which further gave the Nano team a cost advantage. More than half of all the components sourced were allowed to be developed as proprietary technology of the respective supplier so as to gain from other sources of revenue.
- **Technical :-** A big part of Tata's endeavour to produce an affordable automobile was to maintain a profound sense of frugality and question traditional vehicle production conventions to the point of abandoning equipment such as air conditioning, power brakes, power steering, radios, and so on. The Nano is made of tiny pieces that may be manufactured and sent to multiple places separately. The Nano is essentially sold in kits that are delivered, constructed, and maintained by local businesses, e.g., small wheels with mountings, engine, transmission system, etc

The Tata Nano is a notion that can only be realized if it is backed by a genuine and sincere vision. Nano implanted the concept that frugal innovation isn't just about dramatically altering a product's engineering, but also about modifying the business paradigm of providing more value for less money.

C. Aviation and Aerospace

Frugal innovations for sustainable development may have begun as a grassroots phenomenon, with applications in the bottom of the pyramid where scarcity of resources leads to frugal innovations, but in recent years, this basic principle of frugality has been applied to overcome challenges or scarcity of resources in high-tech industries [18].

With an ever-changing global economy, which saw the fiscal crisis of the 2010s and the Corona Virus Disease (COVID-19) of the 2020s, it's more crucial now than ever to focus on efficiently employing money spent on research and development for science and technology developments. Let's have a look at a few instances.

1) Airplane wing design: "Fig. 3" represents one of the examples of frugal innovation in aviation sectors is designing plane wings using bird's wings. In the early 20th-century [19] plane wings were designed keeping in mind strength and durability more than efficiency. Now with the advent of new methods to check for failures like wind tunnel testing, Computational Fluid Dynamics (CFD) and advancements in material properties, efficiency and cost-saving are at the forefront of designing a plane.

Richard T Whitcomb [20] was one of the pioneers of modern plane design. Whitcomb designed winglets in the 1970s after watching birds curl their wingtip feathers upward for greater lift. The winglets we see in modern aeroplanes reduce these wingtip vortices increasing their efficiency and reducing fuel burn. The freely flapping wingtips react and

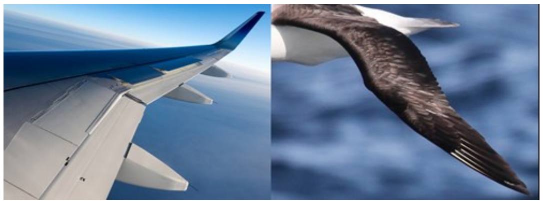

Fig. 3. Albatross inspired wing design for commercial aeroplanes

flex to wind gusts, reducing drag and combating the effects of turbulence. The aeroplane's flapping wingtips are inspired by the Albatross [21]. Albatross, a sea bird can stay for hours in windy weather with little wing extension. These birds have streamlined shapes so that when they are in full flight the air can flow on their surface smoothly. The shape of the bird is also important for producing lift, the increased speed over curved and larger wing areas create a longer path of air. This means the air is moving very quickly over the top surface of the wing and creating lift.

2) SPIKE missile: The Spike missile is the next example of inexpensive innovation. Spike is the "world's smallest guided missile," according to the US Navy, which worked with DRS Technologies on its development. Inertial targeting allows the operator to "snap and shoot" at a target without having to lock it on out to 200 meters [22].

Fig. 4. Spike missile developed by NAVAIR

The Spike missile and reusable launcher cost $5,000 apiece and weigh 4.5 kg loaded, against 22 kg for a Javelin missile and fire control unit. It is a good example of frugal innovation because of its cheap cost and weight, as well as the usage of off-the-shelf components. This capacity also makes it more adaptable than traditional missiles since it is made up of widely accessible off-the-shelf pieces that may be augmented with previously existing off-the-shelf parts. Particularly during times of war and internal strife, when resources are few and demand for this commodity is greatest.

3) Cube satellites: CubeSats [23] are small satellites that have been employed in a variety of applications and disciplines for the past 15 years. They are low-cost, high-volume alternatives to current satellites that are primarily utilized for communication, image sensing, weather forecasting, defence, and other related purposes. By providing cost-effective capabilities, small satellites bring value to both ground-based astronomy and larger space missions. When compared to ground-based astronomy, these advantages include not only the ability to access wavelength ranges where the Earth's atmosphere is opaque, but also dependable, high-precision photometry, long-term monitoring, and increased aerial coverage.

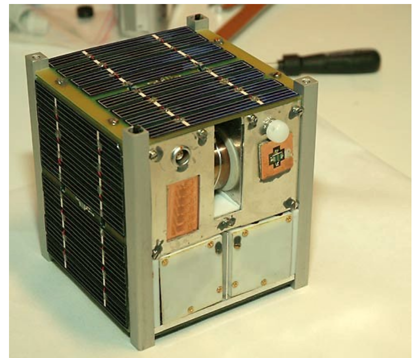

Fig. 5. A typical cube satellite used for communication and image sensing

Researchers in Europe are developing a miniaturized device that will be able to detect carbon dioxide emissions from towns and power plants with pinpoint accuracy [24]. If it works, the device may be launched in the late 2020s atop a network of miniature satellites, allowing scientists to track daily fluctuations in greenhouse gas emissions. The project's authors believe that the three-year, €3-million study would complement bigger efforts to monitor CO2 from space, such as the European Space Agency's proposed Sentinel Earth-observing satellites. They might be operational in the late 2020s if they are authorized.

V. Conclusions

Frugal innovation is experiencing a paradigm shift and is increasingly establishing itself as a complement to traditional approaches to global issues. Changes in demographics and the environment, in particular. As a result, the attitude and structure in which thrifty concepts have historically been studied must be altered. It's worth emphasizing that frugal innovations don't have to rely on reusing existing technology or resources; in fact, there are already examples of these inventions leapfrogging modern technologies to provide resource-efficient and long-term solutions. Close linkages to the circular economy highlight their immense potential for long-term solutions with a substantial socioeconomic impact.

The Tata Nano is a concept that can only come to life if it is backed by a serious and genuine vision. Nano implanted the notion that frugal innovation isn't just about drastically improving a product's engineering, but also about changing the business paradigm to provide more value for less money. Despite the importance of frugal innovations for global health, there is little study on the subject. The goal of this paper was to throw additional light on this problem and uncover patterns of cost-effective healthcare improvements. Our sample of frugal healthcare innovation entrepreneurs hails from the world's developed nations, primarily North America and Europe. In general, compared to established economies, the majority of inventions were initially introduced in emerging and developing countries, with the bulk of them in Africa and Asia.

This chapter identifies emerging technologies with a high potential for promoting the development of affordable and accessible frugal innovations in a variety of other engineering fields, such as 3D printing, mobile services and applications, cloud technologies, machine learning, and artificial intelligence technologies [25]. Frugalism, without a doubt, pushes academics to complement the well-established national innovation system with an international innovation system based on the migration of innovative theories and practices.

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AI Based Early Warning Systems for Production Systems - A Survey

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***Abstract*—Early warning systems are becoming a crucial part of the production systems to reduce unplanned downtimes by leveraging the power of Artificial Intelligence and big data. This survey paper aims to provide a review of the different Early warning systems used in different industries. Finally the drawbacks of these methods and future scope are discussed.**

Keywords—Early warning systems, Production systems, Predictive Maintenance, Survey

I. Introduction

Often it is small modules in production systems, which make it necessary to shut down the plant for their replacement in case of faults. As a result, massive costs are incurred that are out of all proportion to the actual cost. During manufacturing processes, a great amount of data is produced and accumulated in the complex manufacturing field where numerous elements (e.g., human and tangible and intangible resources) interact with one another. Pre-trained Al algorithms can govern a computing infrastructure informed by processed manufacturing data.

Al methods have been frequently used to extract useful information from industrial data. Through training, the techniques infuse intelligence into the systems, allowing them to automatically learn and adapt to changing environments. To demonstrate the methodologies' usefulness in the manufacturing business, the capacity to manage high-dimensional data, reduce complexity, improve existing knowledge, and find essential process relations is presented. These skills enable them to predict the manufacturer's interest in a certain issue, potentially reducing variation in the manufacturing line and increasing efficiency and product quality [15]. As a result, by applying AI algorithms to the production system, the future behaviour of the system may be approximated, and this information can help decision-making.

This paper gives a brief overview of the different AI based early warning systems classified based on the industries they are used in. Finally the drawbacks and future scope of these methods are also briefly explained.

II. Survey Details

A. Chemical Industry

1) AI Based Image Processing: Most pre-existing alarm devices used in chemical and fertiliser industries lack intelligent dynamic gas distribution, detection and control capabilities. These requirements are being realised with AI. The system being proposed uses an automatic gas distribution system, image acquisition and recognition device and a control terminal [1]. The AI based image acquisition system processes the visual input in various ways and the result is sent to the control terminal where the data is verified. The control terminal can remotely control the verification device, thus ensuring the safety of the personnel. Machine vision, remote control and automation tech is used to achieve accurate detection and alarm.

2) Machine Learning using Sensor data: In the chemical industry, an early warning system was built as a sophisticated, integrated monitoring, warning, and notification system. As a preliminary stage, the system allows for direct monitoring of hazardous substance occurrences and concentration levels. Its monitoring sensors are connected to the Amadeo PA system and are independent of other technical systems that govern chemical production for enhanced safety. For the measurement of harmful concentrations, a minimum of two potentially dangerous concentration levels of hazardous compounds are defined. If the measured values fall inside the increased concentration interval, the system notifies the operators in a second phase or notifies the duty members of the relevant staff in unmanned operations. These individuals can determine the cause of the increase in concentrations and take the necessary precautions without declaring a state of emergency. The broadcasting of a warning message is activated after the observed values are above the threshold level for emergency concentrations [17]. The broadcasting activation can be delayed depending on the type of material and applicable restrictions, giving operators more time to check the concentrations using an alternative means and avoiding a false alarm. After the mass warning has been confirmed and activated, the technology enables the automation of all relevant operations.

The system consists of the following elements:

a) The main manned or unmanned control centre

b) Radio-controlled Amadeo PA units, optionally equipped with additional modules to increase the number of inputs for monitoring sensors

c) Sensors monitoring the occurrence of hazardous substances

d) 100 V PA loudspeakers

e) Powerful pressure loudspeakers

f) Emergency beacons

3) Image processing using Adaptive Target detection framework: Target detection framework: Liquid metals are commonly used in chemical industries and nuclear reactors. Since liquid metals may be hazardous, they should be handled very carefully. Corrosion and pressure can deteriorate the structure that handles the liquid metals. Early warning systems, detection of the accident, and prompt steps taken after the incident are the three important phases of monitoring. At present, industries have sensors-based detection. Here the conventional system is integrated with AI to identify indoor and open-air fire situations. This discusses different data collected and investigated from the videos, sensors, and other monitoring systems. The proposed system has a fixed and moving sensing unit, image capturing system, sensor management module, structured, and unstructured data analysis module. These days industries install video surveillance systems, which help improve early detection of cracks, spillage, and fire in the plants and can help avert disasters. Deep-learning algorithms are used to extract the target (crack, leak, or fire) pixel from the background pixels [6]. Image classification, object recognition, semantic division, and current pixel position are important in computer vision-based systems. Here they use a lot of different methods for example Detection of fire using OPENCV and NUMPY, Adaptive Pixel Detection Technique, Adaptive Target Detection Technique etc. It is also highlighted that this framework will help reduce false-positive alerts by fire detection systems R-CNN based, Generic Colour Model-based, vision-based fire, and smoke detection systems in this combined approach will help plug any other safety loopholes. Out of all the techniques, the Adaptive target detection framework gives 98% accuracy [6].

B. Oil and Gas Industry

1) IOT and Machine Learning: Ship collisions and frequent typhoons make it difficult to develop deep water oil and gas resources. Centralised data storage systems can be exploited for real time of ships around the platform and early warning of typhoons [2]. The system predicts the typhoon influence radius and typhoon path forecast. The ships AIS system (Digital Navigation Aid system) is used to monitor the platform and the ships around the sea pipe in real time. Technologies such as Silverlight, ArcGIS API for Silverlight and WCF can be used to realise this system. Silverlight is a cross platform plugin which can be easily integrated into the existing web application. ArcGIS provides capabilities for map development, graphics rendering etc. WFC integrates all technologies and enables developers to build a cross platform solution that works for the existing system.

2) Artificial Intelligence in emergency management: The application of artificial intelligence technology in emergency prevention and preparedness mainly includes emergency plan compilation and emergency support. Emergency plan is a work plan for dealing with emergencies, which is formulated in advance to effectively prevent and control the occurrence of emergencies and minimise accidents and damage caused by them. Intelligent information retrieval can be used to retrieve and predict almost all disasters and emergencies that may occur in the production and operation of the petroleum industry worldwide for specific operations. Data mining is carried out according to the production experience and industrial characteristics of the petroleum industry, and a more scientific, reasonable escape plan is given in the process of emergency plan formulation.

The application of artificial intelligence technology in the monitoring and early warning stage mainly includes emergency information monitoring, risk analysis and assessment, event early warning and so on. Monitoring and early warning are actually based on real-time collected data, including temperature data, pressure data, real-time voice data, and video surveillance data. Machine learning can be used to determine normal data in real time.

The application of artificial intelligence technology in emergency disposal and rescue mainly includes rescue plan formulation, on-site rescue, on-site decision-making and command, etc. The key technologies such as stable emergency communication (airtight space, deep sea, high mountains) and long endurance can realise emergency rescue and rescue operations in any environment.

The application of artificial intelligence technology in the post-recovery and reconstruction stage mainly involves investigation, assessment and accountability. With the combination of AI and big data technology, it can reproduce the history and provide technical and information support for accident investigation and accountability investigation [16].

C. Power Systems

1) Hierarchical Artificial Neural Networks: Conventional fault studies are mainly reactive – 'what if?' – What would happen if a fault occurred. The proposed system uses AI to detect faults in power systems at an early stage using only external measurements from input and output nodes. Hierarchical artificial neural networks are at the heart of the Early Fault Detection system. The system is trained to detect minor changes in states of important components. Standard sigmoid function was selected for the implementation as it bounds its output between 0 and 1. Standard multi-layer is employed in this system. Genetic algorithm and backpropagation are two potential methods which can be employed. Back propagation results in local maxima and this problem can be avoided by using genetic algorithms. Hierarchical distributed ANN (HDANN) showed better results compared to conventional methods [4]. HDANN with 4 ANN units were employed in this implementation. Each ANN unit was trained with approximately 1000 iterations. The desired and correspondingly simulated results closely matched with an accuracy of 99%.

D. Manufacturing industry

1) Big Data: Risk identification can be done through analysis of various data and risk accidents summarised and organised. Backward management methods cannot be used for analysis of large amounts of information. The proposed system uses high tech means with manual management to improve accuracy and timeliness of risk prediction. An evaluation index system is constructed and the evaluation categories are analysed [5]. Based on the evaluation results, early warning intervals can be set and corresponding countermeasures can be taken in response. To increase risk perception and early warning, big data can be used to create a database of potential risk variables based on large amounts of data.

2) Hybrid Early Warning Systems: Physical models, Artificial Neural Networks, and Case-based reasoning can all be used to create a hybrid early warning system in different ways. ANN is a mathematical modelling which can be used for pattern recognition and multi-dimensional non-linear regression. Low computational requirements and parallel structure make them suitable for on-line applications. But the dependency of ANN on data is a weak point. Data from sensors may contain errors which need to be filtered. Model can be run only within the space it has been trained. Errors occur if the domain they model slowly ages due to fouling and ageing. Physical models are derived from physical experiments. The equations describe the relation between input and output. The theories used are simplifications of real-world datasets. Tuning factors of the model produces data closer to measurements. Simulations can produce artificial data that represents the machine behaviour for the full operation range. They often have iterative procedures and thus it is difficult to estimate the computation time. Case based reasoning offers a method to implement experience-based diagnosis for real-world applications. CBR uses a database containing cases and uses these cases to solve new problems of similar nature. The system improves its base of experience when a new case is added to the database. In the ANN-CBR hybrid, the neural network can represent a compilation of the selected domain knowledge from the case library and can act as a decision support in response to its input. Once trained the neural network classifier can handle failing quality of sensor measurements and sensor degradation [3]. Physical model-ANN hybrid uses the calculation speed of ANN for on-line early warning and physical model to train the dataset for ANN. Final adaptation to the real behaviour is done when the ANN is trained with real data and with artificial data from the physical model [3]. Physical model-CBR hybrid extends a sparsely populated case library by incorporating model-based reasoning [3]. In artificial intelligence, agents are a frequent method. An agent can be thought of as something that observes its environment through sensors and influences it through effectors. When building a hybrid early warning system, agents provide a powerful environment for thinking that is independent of application decisions.

3) Long Short Term Memory (LSTM) based model: Models using temporally dependent sensor data were used for NASA's aircraft engine performance monitoring and life expectancy. Six built in sensors were selected and focused on a model based on the Long Short Term Memory (LSTM) to describe system breakdown behaviour and determine the remaining usable life. Furthermore, the capacity of the LSTM to capture temporal dependence was compared to that of several machine learning techniques. It has been shown that the trained model can effectively predict the actual behaviour of the test set and the accuracy of the prediction increases as the length of the prediction decreases [10]. Compared to various machine learning prediction models LSTM performed better in useful life estimation in both datasets than alternative machine learning methods. In a similar study, a data-driven artificial intelligence based modelling approach was used to predict spindle motor, cutting machine wear and malfunctions.

4) Event-Based Supply Chain Early Warning System for an Adaptive Production Control : Intra- and cross-company manufacturing and logistic operations become more vulnerable to unanticipated instabilities as a result of increased complexity. The authors offer an event-based supply chain early warning system that uses event data to detect significant occurrences in the supply chain in real time. RFID can be used as a low-cost automatic identifying system, it is possible to advance the data collection process. Modes: Serious events can be recognised and assessed in real-time by event-based tracking of objects in the network. With early warning information it is additionally possible to safeguard following processes by evaluation and execution of suitable actions in the field of adaptive production control. As an outcome, adaptive situational control of intra-company production processes is made possible [8]. The advantages of this method regarding logistic aims are assessed by using a discrete-event simulation based on a prototypical execution of a cross-company production scenario. As a result, severe incidents can be identified and examined in real time using event-based tracking of network objects. It is also feasible to protect subsequent processes using early warning information by evaluating and executing appropriate measures in the field of adaptive production control. As a result, adaptive situational control of intra-company manufacturing processes becomes conceivable. A discrete-event simulation based on a prototypical execution of a cross-company production scenario is used to examine the merits of this strategy in terms of logistical goals.

5) SVR Model and Fuzzy logic: This early warning system helps waste-water processing station operators take early action and avoid environmental pollution. The model is based on historical data collected by data-loggers to predict future quality of the waste water. To assess the performance of four time series data consisting of PH, temperature, TSS and COD are used.

To construct an early warning model for recognizing environmental pollution of waste-water in industrial zones, researchers used two soft computing methods that support vector regression (SVR) and fuzzy logic. The embedding dimension space for a time series is discovered using a false closest neighbour approach, and a model for forecasting the quality of wastewater in industrial zones is built using fuzzy logic and SVR.

Data is collected from a wastewater processing station to build and test the model. The experiment results show that the SVR model obtains the results more accurately than the fuzzy model for most of the case study data [19].

The fuzzy logic model gives better results than the SVR model because the fuzzy logic model tolerates noise better than the SVR model. In addition, training the fuzzy logic model requires less time than the SVR model because training the fuzzy logic model only required using the training data set once, while training the SVR model required the training data set several times. Therefore, the fuzzy logic model for noisy, real time and least accurate parameters can be applied. Otherwise, the SVR model is preferred.

6) Wireless Sensor Network - enabled Alarm System: Equipment maintenance is important in intelligent manufacturing since it directly affects the equipment's service life and production efficiency. Existing equipment maintenance methods rely on system alarms, and an operator notifies equipment maintenance employees of any issues. The fault then needs to be exactly located and resolved, leading to a shutdown in the production process. With the support of manufacturing big data, device data can be logged in at real time, including device alarms, device logs, and device status, in order to evaluate the health condition of manufacturing equipment and preemptively detect breakdowns. Therefore, active preventive maintenance is proactive and can find problems earlier.

Recent research achievements, such as the radio frequency identification (RFID)-enabled manufacturing execution system, and the wireless sensor networks (WSN)-enabled alarm system [18] have provided a preliminary basis to enable the design of active preventive maintenance for intelligent manufacturing.

Three main parts of this method include

1. A cloud-based system architecture for collection of manufacturing big data is designed for industrial environments, which contributes to the implementation of active preventive maintenance.
2. Data processing including real-time active maintenance and offline analysis and prediction in the cloud is provided.
3. The real-time active maintenance mode and the traditional maintenance mode are compared. The offline prediction algorithm is then implemented in a machining centre to validate its viability and effectiveness.

The manufacturing big data method used for active preventive maintenance has the capability to hasten execution of Industry 4.0.

In general, manufacturing big data can be categorised into three sorts: device data, product data, and command data. Using a cloud platform, collected manufacturing big data can be studied further and used to generate ground-breaking applications, such as active preventive maintenance, optimization of a production line, and energy consumption optimization.

7) AI Safety in Manufacturing: According to analysts, falling accounts for 40% of all safety occurrences, which can be easily avoided. AI helps improve the safety of employees and physical assets in manufacturing environments by combining IoT technology, real-time data collecting, and advanced analytics. In the area of security, AI encompasses everything from collaborative robots (cobots) to machine vision technologies to machine learning (ML) to deep learning algorithms and models. Noncompliance can be monitored by AI systems. People's activity inside the factory can be monitored using computer vision systems or sensors. If people are not following the rules, early warnings can be given, which can be used to send alerts or emails to regulators, reducing misbehaviour and enhancing internal safety. Factory Wearable sensors can be attached to a jacket, a wristband, or a helmet. These sensors can transmit data and monitor activity in potentially dangerous workplace environments. Machine learning and non-progressive data analytics can be used to detect events and generate warnings before a catastrophic accident happens [14]. These technologies, similar to autonomous vehicles or self-driving cars, can be used within a plant, where many forklifts can communicate with one another using sensors and technology. They are able to avoid colliding with and bumping into items within the tree. There will never be a perfect AI system. As a result, the major goal with AI is to accomplish 90-95 percent, while people are trained to avoid the remaining 5-10 percent. Thus, AI can eliminate most of the repetitive tasks.

8) Predictive Maintenance of Machine Tools System using AI: External sensors put on the machine can translate the conditions of the machine tool in use into signals (for example, accelerometers, microphones, dynamometers and thermometers). Raw analog signals must first be treated to remove undesirable frequency bands before extracting valuable information. The next step is to extract features from the processed signal and compress the data in order to generate condition information. There are three types of AI techniques: supervised, unsupervised, and reinforcement learning [11]. The retrieved features are trained with their respective labels using supervised learning. Unsupervised learning develops estimated models rather than labels for each data set. The reinforcement learning approach learns from rewards and punishments before creating a policy to accomplish the goal. The results of the AI model can be estimated once it has been trained. Cutting tool condition monitoring and bearing condition monitoring are among the simulation outcomes.

E. Pharma Industries

1) AI-enabled risk detection: AI-enabled risk detection: Risk identification is an important aspect of the pharmaceutical production process. Risk should be removed from the patient as much as feasible, according to the Quality by Design principles. This entails safeguarding them against flaws in the manufacturing process or in the raw ingredients. And that involves identifying weaknesses as quickly as feasible. Quartic.ai has opted to collaborate on a new AI-based risk detection engine with Sparta Systems [13]. Without data science training, the software will soon identify dangers in the pharmaceutical production process and present consumers with quality information in real time solutions. Together, the two businesses develop an "in-field" data gathering system that uses machine learning to detect growing deviations and odd process behaviour (Quartic), as well as proactive quality assurance (Sparta).

F. Food Industry

1) IOT based traceability for Food supply chain : Customer's health awareness is of extreme significance. Food can become contaminated at any point during production, storage and delivery. Hence, it is of utmost importance for the perishable food supply chain to supervise the food quality and safety. Traceability system offers a comprehensive information on food and thereby guarantees food quality and safety. The study puts forth an IoT-based traceability system that utilises RFID and raspberry pi-based sensors. The RFID plays a main part to track and trace the product; thus, it can avoid counterfeiting and distribution of low-quality food products along the supply chain. The proposed system uses the temperature-humidity sensor for raspberry pi to collect data on the atmospheric conditions of perishable food during distribution and storage. Moreover, the machine learning based forecasting model is put into practice to predict temperatures, so that early warning can be presented by the system if the predicted temperature exceeds the normal range. The results showed that compared to the traditional methods, the proposed system is capable of tracking products as well as predicting sensor data accurately and effectively [7]. Finally, a forecasting model based on machine learning is utilised to estimate the changes of temperature, so that controlled storage can be maintained.[7]

G. Coal Industry

1) IOT based early warning system : Deadly accidents associated with underground coal mines necessitate the implementation of high-level gas monitoring and miner's localization approaches to help with underground safety and health problems. For improving safety management and preventing accidents in underground coal mines, this study presents a real-time monitoring, event-reporting, and early-warning platform based on cluster analysis for outlier detection, spatiotemporal statistical analysis, and an RSS range-based weighted centroid localization algorithm. The suggested platform uses the Internet of Things (IoT), cloud computing, a real-time operational database, application gateways, and application program interfaces to seamlessly combine monitoring, analysis, and localization methodologies. The prototype has proven useful at the Hassan Kishore coal mine, which is still in operation. When compared to their commercial equivalent, sensors for air quality metrics such as temperature, humidity, CH_4, CO_2, and CO produced great results, with regression constants always coming out to be more than 0.97 for every parameter. In the tough environment of underground mines, this system allows for real-time monitoring, abnormal event detection (>90%), and verification of a miner's location (with 1.8 m of inaccuracy). The development of an open source, configurable, and cost-effective platform for efficiently improving underground coal mine safety is the study's key benefit. This system has proved important for solving the issues relating to accessibility, serviceability, interoperability, and flexibility with respect to safety in coal mines.[9]

H. Automotive Industry

1) Simulation-based Early Warning Systems in Automotive Industry : The Simulation based Early Warning System elements have a variety of roles and tasks. A Web Service software is designed to provide help with the communication between various software applications running on discrete platforms over a network. They enable software and services from a variety of locations to be combined seamlessly to an integrated service and to be reused within an infrastructure [12]. The abilities and characteristics of material flow systems can be described by a specific spectrum of data. The first group holds data which is deterministic and independent from the present condition of the system. The second group is dynamic data which describe the current system state. This data is given by different production planning systems, production control centres or planning and documentation databases. A RFID system typically contains two main components: RFID tag or transponder and RFID transceiver as an antenna reader combination. Passive tags do not demand an internal power source, whereas in active tags a power source is a necessity. Depending on the standard or frequency they work with and the material they are attached to, the distance between a passive tag and reader can range from a few millimetres.

III. Conclusions

In the industrial environment, the requirement of robustness and real-time processing plays more important roles. For example, deep learning, which has proved successful in image recognition and natural language processing, could make use of stored data but may not be appropriate in active preventive maintenance. Algorithms which may not be that advanced but with expert knowledge might lead to better performance. There are also some challenges like standardisation of processing, management of multisource data, data privacy, the complex nature of IoT-based platforms, and autonomous sensing. Now standing at a new historical starting point, data resources have already become the whole social and economic development under the era of big data and artificial intelligence. At the same time of technological development, big data risk management cannot be left behind. It is very important to establish a closed-loop management chain of data security protection.

Real- time identification of critical events and early implementation of appropriate measures enables significant reduction of the consequences of unforeseen disruptions. Further work is needed on the crosslinking between early warning information and measure determination in the field of adaptive production control. Furthermore, the technology of the eEWS has to be investigated with particular regard to performance (e.g., accuracy and timeliness of early warning information) and cost-effectiveness.

In Manufacturing industries, the estimated time before failure is being successfully calculated by using a machine learning based predictive maintenance system using IoT data. Also Pd.M. systems are being successfully developed using AI algorithms to represent the conditions of the components in the system. However, the measurements are affected by many disturbances. The collected values contain a substantial amount of noise which causes the embedding dimension space of the time series to be large. This value not only affects the accuracy of the model but also affects the training time. In the future a Hilbert Huang Transform can be used as an adaptive filter to denoise the collected time series data before finding the embedding dimension space and building the model. This work will decrease the model's complexity and increase the accuracy prediction. In future, other types of low cost IoT sensors might be utilised, while machine learning methods can be used to improve the performance of Early Warning System.

Adaptive analytics framework may prove efficient and reliable in handling and mitigating the hazards resulting from the fluids and liquid metals. Also, this framework may help in better monitoring and much earlier prompt detection of leakages. It is also highlighted that this framework will help reduce false-positive alerts by fire detection systems R-CNN based, Generic Colour Model-based, vision-based fire, and smoke detection systems. There is also a need for an efficient image management system to help better the fire hazard prevention system.

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Monitoring of KPI's like Delivery Reliability, Utilized Capacity, and Idle Time in Production Systems

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***Abstract*—Monitoring of the Key Performance Indicators (KPIs) has become a crucial aspect in almost every production system. It helps organizations in quantifying their progress and determining how to improve their operations in order to minimize costs, increase productivity and make use of the production systems efficiently. In this paper, we have discussed the monitoring of three major KPIs delivery reliability, utilized capacity, and idle time. Since every production system is unique in its own way, we have mentioned different methods to monitor these KPIs.**

***Index Terms*—Monitoring of KPI, Monitoring of Key Performance Indicator, Delivery Reliability, Utilized Capacity, Idle Time.**

I. Introduction

A Key Performance Indicator (KPI) is a quantitative measurement tool used by the manufacturing industries to measure its performance over time. KPIs are typically used by companies to monitor, analyze, and optimize operations in order to enhance efficiencies. Knowing and measuring the right KPIs is vital to the health and faster growth of a production plant. Monitoring KPIs is important because it helps to measure a company's progress, monitor its health, analyze patterns over time, solve problems or capitalize on opportunities, make critical adjustments, and stay on track.

Delivery Reliability is a metric that shows the percentage of products delivered on time, with a goal of 100%. Measuring delivery reliability is crucial because it determines a company's success or failure. When a company delivers products to customers on time, it builds customer loyalty, which leads to retaining the existing customers. Aside from that, if employees can complete 100 percent of their deliveries on time, it will keep their motivation high. To achieve delivery reliability, the production schedule must be realistic, material inventories must be accurate, and quality must be prioritized.

Capacity Utilization (CU) is generally defined as how efficiently the company is using its production capacity.it can be also defined as the ratio of observed output to the designed output of the production system. The terminology that is generally used while defining capacity utilization is that it is a relative index that gives the rating of the used capacity of the resources. If the Relative index shows 60% then it means only 60% of the available capacity is used in the plant. This is one of the major KPIs and generally relates between the output produced using the installed equipment and probable output which could be produced out of it.

Idle time is a period when the manufacturing process is on hold and no products are produced. This may occur due to multiple reasons such as maintenance, breakdown, human errors. Employers may face substantial consequences if staff is not engaged in productive tasks. According to a 2018 Harvard Business School study, 78.1 percent of workers experience involuntary idle time on a weekly basis, costing businesses an estimated $100 billion each year [1]. Idle time is of two types:

- Normal Idle time: This is mandatory in any working environment and cannot be eliminated. This represents the amount of time that is getting wasted and cannot be avoided and the employer must bear the labor cost of this time. It is best known and referred to as "downtime".
- Abnormal Idle time: The amount of time wastage that occurs due to errors or the amount of time wastage that can be avoided by taking precautions is the abnormal ideal time. A

labor strike, for example, is unusual idle time that may, in many situations, be managed by management. In any firm, time management is critical, especially when there are large fixed expenditures. Depreciation costs are incurred when machinery or equipment is idle, and output productivity is reduced.

II. Monitoring Delivery Reliability

The industrial market is shifting from seller to buyer in past few years. It is important to achieve high delivery reliability to meet the increasing importance of customer service. The difficulty of this was evident during the coronavirus pandemic when quarantine and other restrictions made deliveries unreliable [2]. As a result, entire supply networks were unable to meet their logistical objectives. Therefore, the situation in the manufacturing industry is becoming dynamic, unclear, challenging, and ambiguous. Manufacturing industries address these issues by improving supply networks and integrating their supply chains. However, in a volatile, uncertain, complex, and ambiguous environment like this, planning accuracy plummets as the time horizon lengthens [2]. Manufacturing control, which is responsible for carrying out the production plan in the face of unforeseen events, is thus critical and growing in importance. As a result, in order to reduce delivery reliability losses, manufacturing industries must effectively connect to supply networks and monitor data of how reliably they can deliver products. There are various methods on how to monitor delivery reliability, but in this paper, we have discussed Radio Frequency Identification (RFID) technology.

A. Radio Frequency Identification (RFID)

RFID technology has provided a variety of methods for specific problems or to enhance productivity using different applications with different systems because of the benefits of real-time information capturing. In this section, we will explicitly explain a monitor control system structure for the manufacturing line. The RFID technology is combined with a real-time database and a PLC in the production system. The system explained here is adaptable and can be used in a wide range of factories or businesses. In this section, we will provide an implementation of a monitoring and control system for a discrete manufacturing system, the requirements of which have been thoroughly analyzed in terms of universal benefits. We have explained this system with the help of a case study explained by Na LI, Jie TAN, Zhiyuan ZHU in their paper "Monitor and Control System with RFID Technology in Discrete Manufacturing Line [3]."

1) Analysis of process in a Production system: The manufacturing process is meticulously examined in order to track and enhance production efficiency and accuracy. It has been found that there are primarily two challenges that need to be resolved. The following are the issues that exist in the conventional manufacturing industry.

- **Material delivery problem:**
  The process of delivering by worker from one manufacturing location to another will result in some unexpected losses or errors. As a result, certain unwanted material wastes and labor expenditures will be added to the manufacturing costs. However, in comparison with other manufacturing facilities, the cost of production plays a significant role. Furthermore, in a typical production line, additional manpower was required to handle delivery operations. Which in turn results in rising expense of production. To gain a competitive advantage, the amount of time spent working will be raised, and the increasing strain on each worker will reduce efficiency. As a result, the material delivery issue will be a significant factor in an organization's growth and competition.

- **Procedure organization problem:**
  Due to unavailability if real time information of production, as well as the fact that conventional management is often based on experience rather than science and objectivity which in turn makes manufacturing management even more difficult. The experience linked with organization lacks reliability and objective knowledge, causing management to work even more on production. The inefficiency in operation and assessment will result in a waste of labor and an increase in the amount of time spent on individual stock. Due to a lack of correct information on the manufacturing sites, the scientific statistic approach will be unable to determine the creating and winning circumstances. However, meaningful direct commands from the central management are quite crucial in the garment industry. As a result, real-time production state data will be beneficial. In conclusion, the conventional manufacturing process suffers from a lack of information-based linkages between the centralized unit and the operations [3].
  To solve the problem of material delivery, the material to be moved between production sites will be positioned on a track and managed by our PLC-based auto control system. When the material is delivered by employees, this will not result in unplanned losses or errors. The recommended monitor control system has a high level of automation, which saves a lot of manpower and lowers production costs. By reducing worker burdens, it can improve the efficiency of the product. The host computer, on the other hand, may easily organize procedures using the real-time information provided by the RFID reader. This will give the management with constant and objective information on the state of the manufacturing process, such as the rate of production on each manufacturing site or a set of manufacturing sites for a certain manufacturing step. The scientific statistic approach will be able to understand the producing and earning circumstances from reliable data. The manager will then be able to build a better scheduling plan based on this information.

2) Framework for the monitor and control system: In modern factories, it is necessary to have a material handling system that will be able to transport materials efficiently in the process of a manufacturing plant. RFID and real-time database technologies are primarily employed in our solution to create a monitoring and control system. The offered system's structure is designed to be adaptable and may be employed in a variety of manufacturing processes, such as meat processing and IC assembly lines.

- **RFID Technology:**
  RFID is an automated identifying technology with a number of advantages, including large store capacity, flexible memory, and the ability to be programmed. The use of RFID technology in the production process will allow for the collection of real-time data on the physical products engaged in the process [3]. It can improve the production system in the following ways:
  i) Quality Control: The level of quality is of the products is checked in the present manufacturing process by a series of separate production sites. The production must get a series of measurements precisely before the final acceptable check with all of the data obtained by the produce locations prior to the finish of the production method. However, with the help of the RFID tag, data on quality gathered at each production site during the manufacturing process will be monitored in real time throughout the production line. As a result, it can easily meet the quality control need.
  ii) Flexibility: Manufacturing control may now be more flexible due to RFID technology. For a small period, during the pre-configuration phase, the configuration data for programmable robots and production equipment would be loaded into the tag loader, which will follow the raw material across the manufacturing process. As a result, future accessibility to the setting data will be possible. It can even manufacture the lowest quality of a single product without sharing data with each individual product site. Because of its features, such as waterproof, anti-magnet, and high-temperature tolerance, RFID technology is well suited for data gathering and process management at industrial production sites.
  iii) Low Environment Condition Requirement: Dust, moisture, oil, coolant, powder scraps, toxic gases, extreme temperatures, and other comparable factors do not affect the RFID system. Because most glass or plastic labels satisfy the IP67 protection type criteria, they are entirely dust and waterproof. Because the optical lens of the scanner is quickly affected, the RFID system can perform effectively in situations where the bar code cannot be utilized because dust builds or is easily polluted. The data collected by RFID may be utilized to increase manufacturing efficiency and lower the costs.
- **Real-Time Database and Relational Database:**
  In the raw material monitor and control (distribution) process, both a variety of temporal data, and also a variety of production program data, should be kept. As an outcome, additional technology must be deployed to support the system that seems to be watched and controlled. For both real-time and similar products, it is recommended the following fundamentals: To satisfy the requirements of production processes, the next deployment of the monitor and control system will use the Chinese Academy of Sciences' Agile distribution real-time system and Microsoft's SQL Server relational data system. It gives the material movement and monitoring systems a lot of help. The historical data may be retrieved at any moment under the support, providing a powerful way of tracing and control [3]. The Agile real-time database system provides a variety of data types and storage and administration techniques, as well as providing a unified logic data view to external applications.

- **The Software System for Monitor and Control System:**
  By employing a distributed system and centralized control architecture, the software system combines the scattered control system, the process scheduling system, and the decision-making system. the following Fig. 1 depicts the system's software architecture.

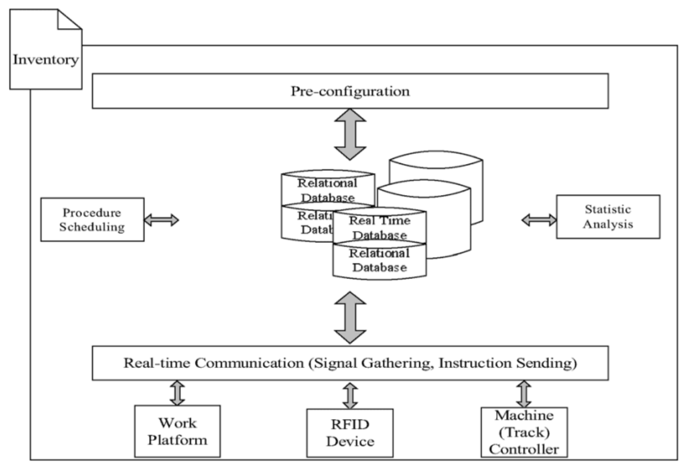

Fig. 1. The software architecture [3]

- **The Monitor and Control System Architecture:**
  Three components that make up the monitor and control system are: the host computer, the electrical control system, and the operation terminal. The central server is in responsible for supervising the whole system's planning. The electrical control system is in charge of the fundamental control of the electrical system. The operating terminal will serve as an intermediary, collecting data from many RFID readers [3]. There are two types of middle-ware that work as functional components to enable flexibility. They are global control middle-ware and data capture middle-ware. The global control middle-ware will primarily focus on providing an unified timing for the whole system, which will include PLC control, real-time database activities, and communication with the operational interface. The data capture middle-ware will primarily support the operation of the RFID system, such as miss-readings and cross-readings. In different circumstances, the implementation will be varied.

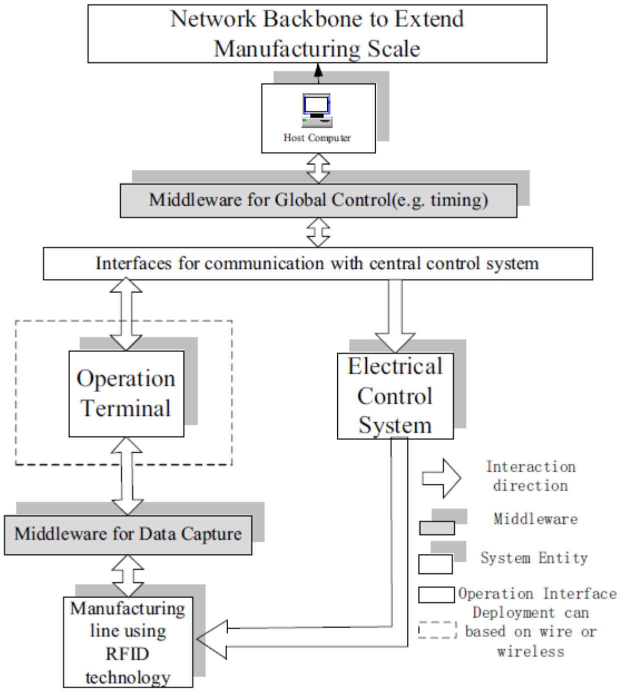

Fig. 2. Monitor and Control System Architecture [3]

3) Implementation: : This section will provide an overview of the monitor and control system implementation mentioned before. The software system used in the implementation is visuals application software that runs on the host computer. Figure depicts the production process flow using RFID technology. Each production site will be in charge of one type of activity. A major guide rail connects all of the industrial locations together (shown as in Fig. 2). For a manufacturing method, the material to be treated is transferred along the guide from the first site. The main guide will branch a sub-guide at each of the production sites to allow materials or unfinished goods to enter or depart the site as programmed in the PLC by the centralized controller [3]. Each of the locations can benefit from the sub-guide track acting as a cushion. The material is automatically transported to every manufacturing location by an RFID reader installed on the main guide, which identifies the material and transports it to the correct production site as pre-configured.
The information collector center will be the RFID intelligent operating terminal. The following are the tasks of the operation gateway

- The system will be able to accept commands from the Central Controller thanks to the bus interface (Host Computer). Then, in accordance with the communication standard, a matching action signal will be sent (drive the electric control to do the corresponding action). Simultaneously, it will send data to the Main Controller based on the Main Controller's instruments or pre-configuration. However, there is still one flaw that has to be addressed: the major CAN bus utilized in the current system is low-cost and widely used, but it has several flaws and limits. The bus's efficiency may suffer as a result of the master-slave working model, which results in poor system real-time communication, communication dependability, network engineering debugging complexity, and high maintenance costs, among other things.
- The operation terminal may assist in identifying the hanger ID received from the main guide, and then begins to manufacture in compliance with the hanger's information. If the hanger recognition job is mostly done by bar code identification, the hanger would need to be in a quiet condition during processing, and would only be identified after being moved into the correct sub-guide according to the main control computer schedule. Because the bar code recognition is always to be read-only, the processed data must be delivered to the Master Controller at the end of the process. The Main Controller and the bus would be responsible for the majority of the loads, while the RFID system would not.
- Simple functionalities for Man-Machine interaction are available on the operating terminal. It may provide important parameters inputs or instruction states, factual info, and instruction showing from user, control platform, and intelligent hanger with a small display and keyboard. Because the system currently uses import devices, the information shown in English exclusively may cause some trouble to users. A comparable intelligent terminal (including readers) is connected to the CAN bus to regulate working states at a separate workstation, each of which works for a different manufacturing process. An intelligent hanger may be loaded with different kinds of apparel and connected to the monitor and control system on the garment production line [3]. Then, in accordance with the need, which has already been put on the radio-frequency card that is received by the reader at every workplace (produce site). The manufacturing line's producing site will thereafter function appropriately as pre-configured. It can significantly minimize the time spent on system scheduling by the Main Controller (Host Computer). Not only is the problem of one production line being unable to create diverse styles of items solved, but the manufacturing process's dependability is also enhanced.

III. Monitoring Utilized Capacity

The capacity utilization measurement is important for determining a company's efficiency in terms of resource use as well as preparing for the future. On the one hand, incorporating capacity utilization into your manufacturing analysis can help you determine places where your production line is wasting or inefficiently utilizing its potential output. Low capacity utilization, on the other hand, can signal that resources are over-or under-allocated, allowing for the better ordering and long-term utilization strategy decisions. You'll need data from a few different sources to keep track of your capacity usage rate such as to collect data regarding your resource capacity—purchase reports, inventory inflows and outflows, cycle periods, and output capacity. You should also track data about your actual output, such as gross production numbers, resource consumption, and total materials intake against output.

$$Capacity\ Utilization = \frac{Actual\ Level\ of\ Output}{Maximum\ Level\ of\ Output} \times 100 \quad (1)$$

A. Capacity Utilization Monitoring using Production Planning/Detailed Scheduling on SAP S/4 HANA

SAP S/4HANA is one of the most widely used Enterprise Resource Planning(ERP) systems in the market, especially among larger and more complex organizations and companies are using SAP ERP in the form of SAP S/4HANA for monitoring Capacity Utilization. Monitor Capacity Utilization app, also known as F1523- S4OP, is used in the newly created Production Planning/Detailed Scheduling integrated SAP S/4 HANA to monitor resource utilization in a chosen area responsibility [5]. This interface then provides you with the list of resources and the level of utilization. That is, which resources are currently being fully utilized or have a capacity overload so that you can quickly react to the critical situation. Furthermore, you can quickly determine whether resources are under strain and whose consumption is within typical limits. There are a variety of profiles to pick from, and the profile we select determines the orders or processes the system considers, as well as the utilization rate percentages it uses to calculate resource capacity utilization [4] [5].

The Key features of this system are:

- You can select the area of responsibility that is which production system or Machine you want to work on.
- You can choose from filters what data exactly you want to analyse.

Fig. 3 is an example of what the data of the selected responsibility will look like. It will feature what was the maximum and minimum utilization capacity and the average of it. It will also show when first overload and under load happened for the first time. This method is really beneficial because it is very easy to detect the bottlenecks.

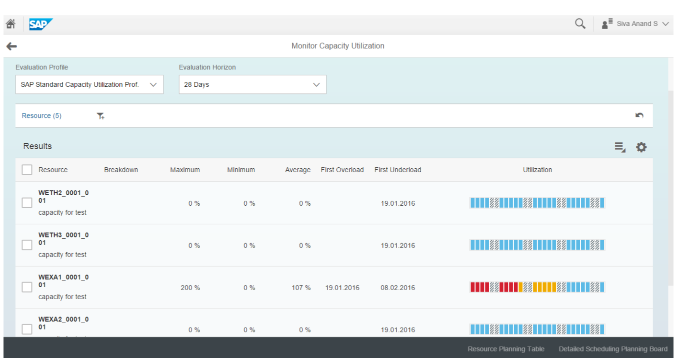

Fig. 3. Monitoring Capacity Utilization app [4]

B. Modified Work Sampling Method for monitoring Capacity Utilization

The next method is Modified Work sampling method used for monitoring of Capacity Utilization [6]. In this company one can find higher Organizational level but comparatively old-fashioned machines. Either a breakdown or preventative maintenance must be the primary cause of the pause. The factory has 4 shifts (3-week shifts + Saturday + Sunday).The capacity utilization monitoring results for the period November 2007–November 2008 are shown in Fig4. Because capacity consumption fluctuates from month to month, the largest failure took place In march 2008, and an annual upgrade was completed during the pause. Capacity is evaluated using a criteria that is 100% and matches the expected monthly output of 60 833 t, and capacity is tested electronically using the produced weight/hour.r. In September, the maximum capacity obtained was 106.25%, or 64 635 t, which is a substantial divergence from the planned level.As a result, shutdowns are rationally linked to the machine and the grade of the given capacity, and they could be avoided by maintaining a maximum monthly capacity of 100%, with others being less. Although there are only 13 months (elements) in the calculation, the average monthly capacity for the observation period is 79.34%, Upper Control Limit(AC) = 100% and Lower Control Limit(BC)= 49.46%, according to the Kolmogorov–Smirnov criteria, Ranges of capacity usage based on the normal distribution legislation on a monthly basis P(λ) = 1.653. Where P(λ) is normality criterion of distribution stochastic function according to the Kolmogorov–Smirnov test [7].

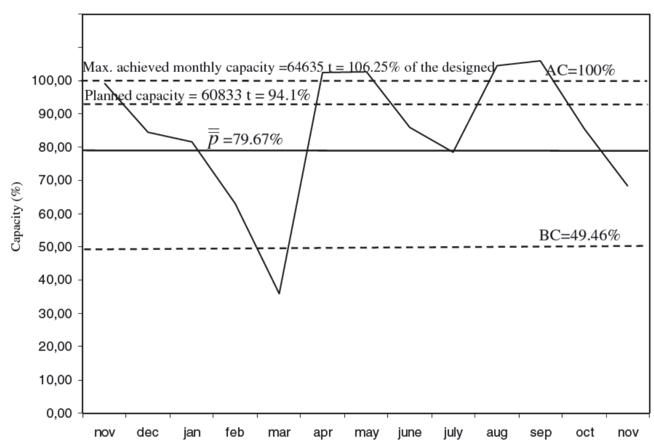

Fig. 4. Mean values of capacity utilization every month for the period 2007–2008 [7]

Fig.5 Despite the fact that capacity utilization is lower per month,It is clear that output observed every day has lower variations in terms of capacity utilization, and that control limits are relatively tight, at 76.4%, AC = 84.13%, and BC = 68.62% . The capacity utilization of one month of monitoring depends on normal distribution law, according to Kolmogorov-Smirnov criterion it is P(λ)= 1.653 [7].

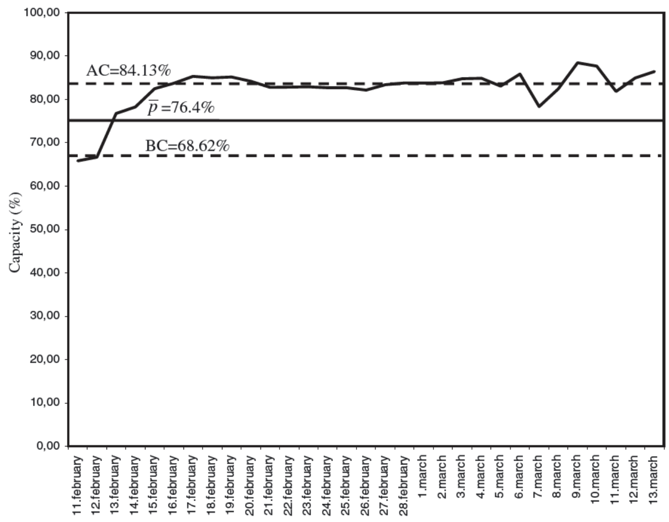

Fig. 5. Utilized capacity per day over the period 11 February–13March 2008 [7]

C. Industrial Internet of Thing(IIoT) based monitoring of Capacity Utilization

Another approach that companies around the world have started to use is use of IIoT as a medium to detect things before they occur. Sudden Breakdown in production systems or Machines can affect the capacity utilization of that system as due to breakdown it can go under severe downtime affecting the production quantity. To avoid this, companies such as HIROTEC, a premium automation manufacturing supplier and LACORIX Electronics are using IIOT as a source of Data Collection to minimize the sudden abnormalities in Manufacturing. The main challenge faced by HIROTEC was Operational Downtime. Most of the machines in the company were running without condition-based monitoring i.e. running until the occurrence of failure. Contacting the maintenance team, assessing the situation and trying to find solution as soon as possible were the subsequent actions that were taken after the occurrence of failure which would delay the production schedules. To reverse this tendency, HIROTEC created a contemporary, automated system that would consolidate all maintenance and operational data previously accessible to HIROTEC into a single source and provide quality specialists with predictive actionable advice.

To carry out the changes in their system, HIROTEC used the ThingWorx IoT Platform and Keepware's IoT Gateway in their system. Due to their implementation the company has seen increase in the visibility into the process of its Computer Numerical Control(CNC) shop and deeper insights into the operations. The process helped them to get greater insights about current needs and priorities and determining the most effective course of action.As a result, HIROTEC has enhanced its Return on Investment and increased productivity throughout the shop. this implementation has also helped them to detect the breakdown if the machine well.Through improved production visibility and the usage of a data-driven system, early identification of abnormalities & maintenance requirements may be achieved. It has also assisted them in increasing asset utilization by lowering downtime and increasing Overall Equipment Efficiency. [8]

D. Capacity Utilization Bottleneck Efficiency System (CUBES)

CUBES is a concept created at SEMATECH to quickly identify bottlenecks by estimating tool through-puts and pinpointing where efficiency losses occur [10]. CUBES distinguishes itself by identifying these losses in a two-dimensional grid. losses and/or consequences due to each E10 equipment state is represented on X-axis.Whereas on the Y-axis, losses and/or consequences owing to tool speed deterioration, rework, installation, and queuing are presented. This method is used to get more productivity from the same set of tools. This task of capacity Utilization is not simple if a manufacturing facility is already running at full capacity. The manufacturing line cannot simply be expanded with more production lots. This might result in issues such as higher cycle duration and high levels of Work In Process (WIP). The capacity of each tool in the manufacturing process is not the same as the capacity of the manufacturing line. It's estimated by taking the lowest individual capacity tool, "the bottleneck," and applying it to the entire manufacturing line. As a result, if this bottleneck tool's capacity can be enhanced, the line capacity will increase as well. The production line's capacity is managed via the bottleneck tool. [10]

It generally focuses on two things:

- Tool Throughput
- Tool Efficiency

CUBES is unique in that it perceives efficiency as a mix of factors in speed and time, both graphically and analytically. The CUBES Model Template is shown in Table I. It analyses the efficiency and throughput of a bottleneck tool using a two-dimensional method (speed and time).

TABLE I
CUBES (E10 TEMPLATE) EFFICIENCY ANALYSIS TOOL [9] [11]

Tool:	Photo Example:	Suppplier:				Model:
Source Data From: Eliminate Test Waffer Case				SOURCE DATA DATE:		
SUMMARIZED INPUTS		Summarized Outputs		CUBES EFFICIENCY(%)	C_{eff}	THROUGHPUT P
		Actual Production				
Theoritical Tool Speed(WHP)	S_t	Speed Efficiency(%)	S_{eff}	OVERALL EFFICIENCY(%)	INDIVIDUAL EFFECT(%)	THROUGHPUT INCREASE ANALYSIS IN WAFERS
Total Time	T_T	Time Efficiency(%)	T_{eff}			
Plan Tool Speed(WPH)	S_p	Tool Speed Loss(Plan vs. Theorey)		O_{Stp}	I_{stp}	
Actual Tool Speed(WPH)	S_a	Tool Speed Loss(Plan vs. Actual)		O_{stpa}	I_{spa}	L_{spa}
Average Batch Size(%Full)	M_f	Batching Losses		O_{MF}	I_{Mf}	L_{Mf}
Other Speed Losses(% Loss)	S_o	Other Speed Losses		O_{so}	I_{so}	L_{so}
Other Time LLosses	T_o	Other Time Losses(ie. Prod. Test)		O_{to}	I_{to}	L_{to}
Standby Idle Time	T_i	Standby/ Idle Time		O_{Ti}	I_{Ti}	L_{ti}
Unscheduled Downtime	T_u	Unschedules DownTime		O_{TM}	I_{TM}	L_{TM}
Engineering Time	T_e	Engineering Time		O_{Te}	I_{Te}	L_{Te}
Scheduled Downtime	T_r	Scheduled Downtime		O_{tr}	I_{tr}	L_{tr}
Non-Scheduled Downtime	T_s	Non-Scheduled Downtime		O_{Ts}	I_{Ts}	L_{Ts}

One of the primary bottlenecks at one semiconductor FABrication(FAB) was the efficiency of the lithography equipment.

Based on the assumptions stated on the summary inputs, the throughput was 2843 wafers per week, as shown in Table I. According to the FAB plan, 3000 wafers had to be produced per week. The biggest throughput loss occurred in standby when the analysis was displayed in CUBES. When questioned why a bottleneck tool had so long standby time and what could be done about it, the response was that the problem was caused by a lack of test wafers and that there was nothing that could be done about it. Following more research, it was revealed that deleting all test wafers would quadruple wafer rework from 10% to 40%. Intuitively, this was ruled out as a factor. However, when a CUBES analysis is performed with test wafers removed and 40% rework, the result in Fig. indicates that the throughput rose from 2843 to 3435 wafers even with 40% rework. This shows that the desired throughput can be achieved and that more research is needed. However, such a rise in rework would have a negative impact on the capacity and cost of the other equipment in the rework loop. These issues are also required to be worked on must be addressed as well. This demanded a thorough examination of test wafers. In terms of rework, it was discovered that some technology process levels were not as important as others. These might be deleted with minimal influence on the rework loop's other equipment. As an outcome, the predicted throughput was achieved. This shows that, with the use of "what-if" analysis methodology, a solution that would not have been explored otherwise might be analyzed and hence implemented [9].

IV. Monitoring Idle Time

Idle time plays a major role in the decrease in production, rising production costs, ineffective machine utilization, increased manufacturing lead time, and increased work in process; therefore, to reduce idle time, a method of optimizing manufacturing process activities and effective queuing up of manufacturing process activities are used [21]. Changes in the activities are made to reduce idle time; however, the machine used in the manufacturing process must also be redesigned to make it easier to perform the optimized activities. It's preferable to replace "elimination" of non-value-added activities with "optimization" of non-value-added activities that take up idle time [21]. Because of its relationship to productivity and corporate profitability, downtime is a hot topic in manufacturing. Reducing downtime in production processes, such as electrical-components manufacturing units, has thus become a need, as it also helps to maximize equipment up-time. Each product's loading time, downtime, and machine availability can be calculated using the expressions below.

$$Loading\ time = Scheduled\ Operating\ Time - Downtime \tag{2}$$

$$Machine\ Availability = \frac{Actual\ Production\ Time}{Planned\ Production\ Time} \tag{3}$$

$$Downtime = Scheduled\ Operating\ Time - (Availability \times Operating\ Time) \tag{4}$$

Apart from the above-mentioned equations Up-time, Mean Time to Repair (MTTR), Mean Time to Acknowledge (MTTA), Mean Time Before Failure (MTBF) also play an important role in the monitoring of downtime in production systems.

- Up-time: The amount of time in percentage when the production system is functional to the total amount of time.

$$Uptime = \frac{Total\ Time\ -\ Downtime}{Totaltime} \tag{5}$$

- Mean Time to Repair (MTTR): The amount of time it takes to repair the system after a breakdown includes both times for repair and testing if required.

$$MTTR = \frac{Total\ Downtime}{No.\ of\ Incidents} \tag{6}$$

- Mean Time to Acknowledge (MTTA): The amount of time between the detection of incident or breakdown to responding to the incident.

$$MTTA = \frac{Time\ to\ Acknowledge}{No.\ of\ Incidents} \tag{7}$$

- Mean Time Before Failure (MTBF): It is the meantime between consequent failures.

$$MTBF = \frac{Total\ Time\ -\ Downtime}{No.\ of\ Incidents} \tag{8}$$

Idle time can be monitored using various methods, here we have explained the Kanban production control system which uses Kanban board software to analyze idle time, and Miniterms 4.0 method which uses IIOT for monitoring.

A. Kanban production control systems

Kanban production planning and control literature may be traced back to the early 1980s when the Toyota Production System was introduced to the United States [17]. Kanban is a system for scheduling, releasing, and controlling material movement depending on downstream demand. This pull philosophy has certain appealing properties, such as reduced congestion and thus greater controllability than standard push mechanisms [18]. The system aims to reduce system inventory to the absolute bare minimum required for continuous output. As a result, the usage of Kanban limits total inventory, however variations at individual workstations may result in lower-than-expected inventory levels across the system and has a fast-flowing process which results in a reduction of downtime [19]. Kanban systems emphasize continual process improvement to decrease statistical volatility in terms of process time, quality, and workstation output to boost system functionality. This system is very efficient in monitoring and reduction of downtime.

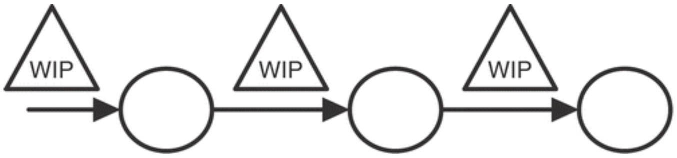

Fig. 6. Kanban production system [19]

In the modern era, all production systems are using tracking and monitoring devices such as sensors, trackers, etc. Most of the manufacturing units use Internet of Things (IOT) based management systems that monitor and process the data from hardware such as programmable logical controllers and display in applications.

One such application or monitoring software is Kanban board. It is software used to track and monitor the activities in the Kanban production system such as functions, workflow, work in progress, cycle time downtime, etc. In the Kanban board, we also get the data analyzed from sensors about the downtime of every machine, robot, conveyor, etc. and these can be monitored in real-time. The Kanban system is a pull system so if there is any problem or issue in the flow the whole production cycle may shut down so the sensors closely monitor any deviation or issues with the machinery in the production cycle. So in the Kanban board, we also have a separate system for monitoring downtime known as the downtime analysis board.

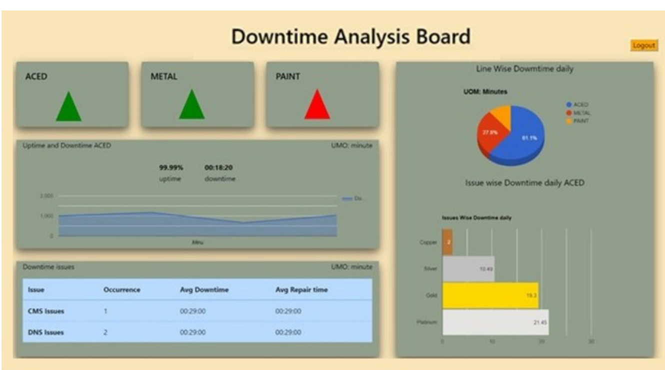

Fig. 7. Downtime analysis board [11]

Above is an example of a downtime analysis board used in the Kanban board where we can monitor downtime of functions such as Aced, Paint, and metal. The green color indicates the system is functioning properly and red indicates an issue with the system or that the system is down. It also provides pie charts and graphs of occurred downtime incidents and helps in the smooth flow of the production process.

B. Mini-terms 4.0

The process of operation of a plant or production unit can be stated as long-term, in the unit functions like machines, workstations, etc. are termed as short-term, then operations performed by an individual robot, conveyor, etc. is specified under mini-term [12] and lastly, individual components function such as gears, relay, etc. are micro-terms. A mini-term is a machine component that can be replaced more easily than any other component by maintenance personnel [13].

Now in a production plant sensors are attached to all the functional machines to monitor their movement, amount of time taken for a sub-task, amount of power consumed, and also to check for any chances of failure of the machine [14]. These sensors are connected to the machines and only a programmable logical controller is required in this setup. Now as the production line is functional these sensors gather all the required data and sent it to the computer. From there we can individually get the idle time of each machine and cycle times of each machine and we can also calculate the idle time of our production site [16]. This system is being used in most factories of Ford Motor company all around the globe.

Real-time calculation of idle time is done as shown below; First of all, we will define the idle time of facility x as

$$Id_n^* = Max(S_n^*, B_n^*) \tag{9}$$

Here the component to be produced is n, now the idle time of facility x can be termed as Id_n^*

Blocking and starving time of the component in production can be termed as B_n, S_n. Now the total cycle time of the facility is termed as T_cT_n. Now $T_cT_n^*, S_n^*, B_n^*, Id_n^*$ are the theoretical values but when the production unit is fully functional it is affected by the reduction in velocity. Now;

$$T_cT_n = T_cT_n^* \times v_n \tag{10}$$

From the above equations, the idle time of the facility can be deduced as

$$Id_n = (T_cT_n^* - T_cT_n) + Id_n^* \tag{11}$$

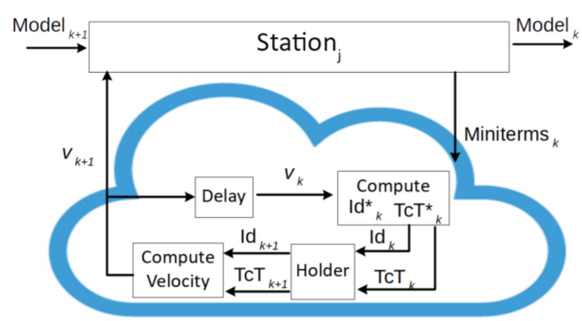

Fig. 8. The dynamic control system used in mini-term 4.0 [14]

The above formulas and methods were referred from an experimental setup in a manufacturing unit at Ford Almussafes factory (Valencia) [15].

V. Conclusions

The primary objective of KPIs is to keep track of various departments and activities within an organization. They assist in determining which processes are successful and where there is room for improvement and cost reduction. Which KPIs should be monitored and how they should be monitored is entirely dependent on the company and its business model. We have described the methodology that we believe is best for monitoring delivery reliability, utilized capacity, and idle time KPIs.

The industrial world is transforming day by day due to digitalization. Therefore, incorporating methods that use digital modes for monitoring will always be beneficial for the company to gain superiority in the market. As a result, we believe that RFID technology can be used in conjunction with a PLC to monitor delivery reliability. If we talk about Utilization Capacity, use of SAP S/4HANA platform is the best example of how digitalization has turned some tedious jobs like monitoring utilize capacity into a simple work. It helps the manufacturer to have a quick overview of how the machines are working with respect to the actual capacity. Adding to it, Companies have started implementing IIOT by using softwares like ThingWorx IoT Platform and Keepware's IoT Gateway into their systems which helps them to predict the problem like Breakdown well before it could happen. Through this the customer Monitoring idle time can be difficult and prone to errors, if performed using conventional methods. However, when Mini-terms 4.0 is used to monitor idle time using IIOT, the results are accurate, and it is also easier to analyze data because the information is available digitally.

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Digital Technologies Monitoring KPIs in Production Systems.

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***Abstract*— This paper provides brief description of various digital technologies implemented in production systems to monitor Key Performance Indicators (KPIs). These KPIs also serve as forecasting tools for production systems and act as decision support. There are some important KPIs in the Manufacturing industry to be analyzed and monitored, and those are Overall Equipment Effectiveness (OEE), Delivery reliability, Idle times and Down time. Adapting digital technologies like IoT, Digital twinning, VR, SCADA, KPI-ML, Miniterm, APS, AI, Cloud computing, for effective monitoring the KPIs which finally provides a better performance evaluation of production systems,**

Keywords: KPIs, Manufacturing, OEE, Downtime, Idle time, Digital technologies, Production systems

I. Introduction

Key performance indicators, or KPIs, are commonly used to measure current activity and to evaluate production systems. Most of these indicators are used after a process has been executed. KPIs are a collection of measures that focus on the aspects of organizational performance that are crucial to the organization's success. The production system uses late information or prior indicators, such as scheduling based on dispatching rules. Production system monitoring is a key activity that investigates problems in business performance and generates alerts about their presence and source. It is one of the most important roles for businesses since it allows decision makers to take remedial steps sooner rather than later, but it is also a difficult action because to the vast volume and fast speed of data that must be processed. Traditionally, systems monitoring has been based on the evaluation of the aggregate values of KPIs by users who check the scorecard on a regular basis to ensure that everything is in order. Adapting digital technologies in monitoring KPIs makes it possible to predict the information and make better decisions. In Below sections, different technologies monitoring some important KPISs are explained.

II. Overall Equipment Effectiveness (OEE):

The overall equipment efficiency (OEE) is an extensively used KPI for measuring equipment efficiency. OEE is a quantitative indicator of utilised capacity that is used in a range of industries. The OEE was introduced by Nakajima [1]. The availability of equipment and the efficiency of the process is multiplied by the product quality factor to compute OEE [2]. Measurement of OEE allows manufacturers to measure the percentage of productive manufacturing time and OEE can also be used to assess a system's availability, performance, and quality. Many times, the equipment in an industry cannot operate at its optimum level due to some losses. The main objective of OEE is to spot these losses and develop solutions to eliminate them. OEE measurement tool is powerful to find out the losses in a company's existing operations. It is difficult to improve machine OEE without measuring it, so OEE monitoring systems are important [3].

In the absence of data collection interfaces, companies could only collect data manually using paper. The data collected during manual data collection is then put into excel for data analysis and to generate OEE reports. This method is both time consuming and inaccurate. A proper monitoring system can be established in order to collect the data needed to not only verify that production processes run smoothly, but also to examine the processes' behaviour over time. Digital technologies can be adapted in production systems for monitoring OEE resulting in increase in utilised capacity of the machine and production systems.

1. Monitoring OEE Through SCADA System:

SCADA (Supervisory Control and Data Acquisition) systems are particularly well adapted to monitoring regionally distributed manufacturing systems [5]. They are primarily utilized as supervisors, despite the fact that they can do some controls. Figure.1. shows an example of a typical SCADA architecture.

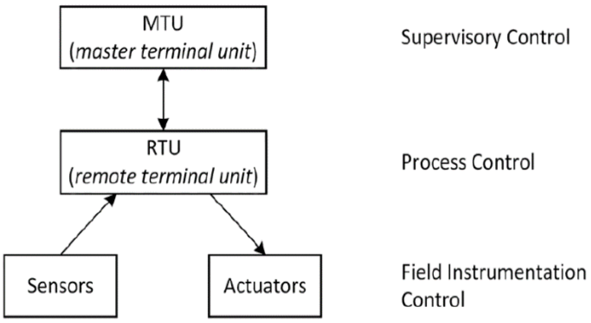

Fig.1. SCADA system 3-Layer Architecture.[4]

Actuators and sensors are responsible for gathering input signals and supplying control signals to processes. RTUs (Remote Terminal Units) are PLCs (Programmable Logic Controllers), which make up the process control layer. SCADA systems, on the other hand, can be used to monitor both local and remote equipment (factory level supervision) [6]. PLCs are strong devices designed to endure the harsh circumstances seen in the industrial sector. Using a PLC, a set of functions like arithmetic, logic and monitoring can be programmed and so the machine and process can be controlled. In the PLC, it is quite common that workers are able to check the status of processes using HMIs (Human-Machine Interfaces). Monitoring and control is completed by a MTU (Master Terminal Unit), which is typically a computer, which gathers data periodically from the process control layer. Alarm management, data logging, process charting, and reporting are just a few of the MTU's features, making it a powerful tool for company management.

LabVIEW - Laboratory Virtual Instrument Engineering Workbench from National Instruments has long been used to design industrial monitoring systems. The DSC (Datalogging and Supervisory Control) module in LabVIEW is used to build SCADA systems that connect with PLCs and store tens of thousands of variables in the Citadel database.

The data acquired on the production processes must be recorded in a monitor application for future study. Datalogging is what it's called, and it's easy to do in LabVIEW with the Citadel DB that comes with the DSC module. On each phase of the production lines, the relational database MySQL enables for the logging of process data and the registration of process characteristics. On the main HMI screen, by clicking on the corresponding button, gives access to specific monitoring for a given production lines.

The Performance button on the main front panel can be used to display the KPIs for each manufacturing line. The current value as well as the evaluation of the selected KPI throughout the specified timeframe are reported in a graph. The data analysis, as well as the start and end dates, are all chosen by the user. With the OEE percentage numbers, the availability (%) and efficiency (%) are displayed.

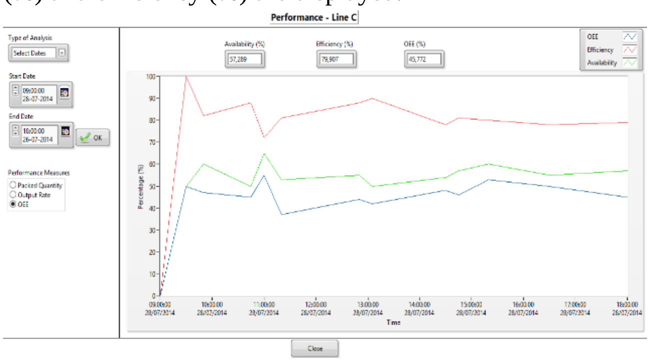

Fig.2.HMI for OEE monitoring [4]

2. Digital Twinning (DT) Technology:

It is possible to increase industry efficiency by combining physical machinery and devices with sensors and software to forecast, control, and plan. The Digital Twin (DT) is a key technology that allows physical machines, equipment, material handling and storage, as well as real-time manufacturing selections, to be connected. The process of collecting data in real time is an intriguing feature of DT. The essence of DT is the linking and synchronization of data connected to the physical product and information included in the virtual product. The three essential elements of the DT framework are physical space, virtual space, and connectivity parts [7]. The five components of the DT framework are digital space, virtual space, connection, data, and service.

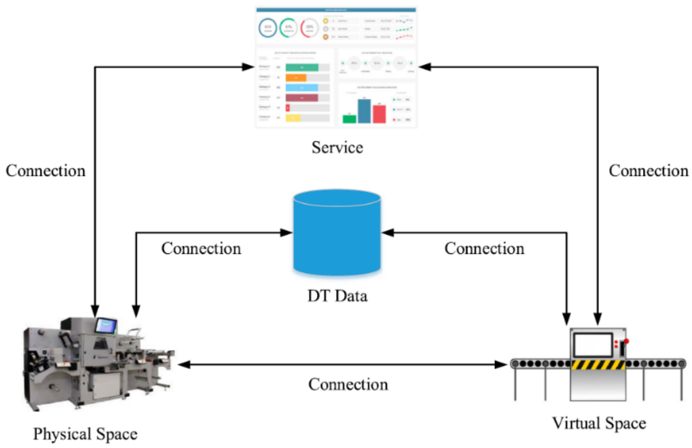

Fig.3. *The Elements of DT [8]*

DT contains both static and dynamic data. Geometrical dimensions, bill of materials, procedures, and order data make up static information and dynamic data are made up of data that varies over the course of a product's life cycle [9]. To aid the operator in monitoring production, DT visualizes production and its components in real-time. The DT approach is used to develop a machine's digital dashboard. A dashboard can be used to monitor an entire system by representing a DT on a macrolevel. Dashboards provide organizations with information on their performance, allowing them to track progress towards their success.

To build DT for machine monitoring, a general design framework is presented. J-Mobile was used to develop the digital dashboard. J-Mobile is a software program that allows you to build an industrial IoT (iIoT) platform that fully covers connectivity, device management, process management, and data visualization for the lowest levels of the architecture. The machine's status, OEE, order scheduling, and alarm functions can all be seen on the digital dashboard. The digital dashboard gets data from the HMI, while the HMI gets data from the PLC.

Digital dashboards offer informational support for monitoring a machine in real-time using these five phases: diagnosis, requirements, template development, checking of necessary resources, and implementation. These five phases result in the development of the DT intelligent module, which has three key functions: real-time monitoring, OEE, and work order scheduling. Machine parameters can be shown in real-time to assist the operator in determining machine status, output quantity, and operating time. OEE evaluates machine availability, performance, and quality based on machine productivity.

III. DOWNTIME

The breakdown and maintenance of equipment are one of the primary causes of poor performance and productivity of the equipment. Basically, there are two types down times [10]. The first type is caused by breakdown of machines due to operational failure which we have to avoid and the second type is intentional breakdown to inspect. Currently there are different digital technologies are implemented to monitor down times. Some of them are discussed here.

1. Condition based monitoring:

Wireless strain measurement is used in condition-based monitoring (CBM) to predict machine failure before it occurs, thus reducing breakdown time and maintenance costs [10][11]. This application is primarily used in mining operations. This system consists of series of intelligent sensors employed at various positions and data management software. Sensors collect data and send them to the software [12][13]. The software compares the data acquired from the sensors with preset values by using conditional statements; any abnormalities are sent to the maintenance team using the GSM module and thereby helps in reducing breakdown time to minimum. A maintenance process could be viewed here as maintenance carried out based on the need indicated by automated condition monitoring systems, i.e., the machines are maintained according to their priority.

2. Digital Twinning:

Digital Twinning along with Artificial intelligence and machine learning is one of the revolutionary applications in the context of smart factories. Digital Twins and artificial intelligence technologies can revolutionize the future of manufacturing. Offering great capabilities that contribute to Industry 4.0, Digital Twins and AI combine to allow working conditions simulations to occur in real time, as well as decision-makings related to important parameters in manufacturing[14][15].

Digital Twins are the virtual representations of resources organizing and managing information and being tightly integrated with AI, ML and cognitive services to further optimize and automate production. Abburu et al. defines three types of digital twins: 1) digital twins, 2) hybrid digital twins, and 3) cognitive digital twins. A hybrid twin is a digital twin, and a cognitive twin is a hybrid twin. A digital twin is a physical replica of a physical system. A hybrid twin that uses a variety of data sources (such as sensor data, databases, simulators, and so on) contains a collection of interconnected models, whereas a cognitive twin is proactive and learns on its own. [16].

Digital Twins will include, but not limited to [16]

- Each piece of equipment is controlled by a Digital Twin at the equipment level,
- sub-blocks that will allow for the construction of equipment level The Digital Twin,
- Linking Digital Twins to Existing Control Systems,
- Digital Twin at the process level that will control equipment within the process and
- A plant-level Digital Twin will control the entire plant's operations.

The data gathered from different sources like sensors, operational data input, automation system input will be analyzed for understanding the situation of the machinery. A virtual representation of this machinery was shown to the operator through digital twinning. Smart components that used sensors to collect real-time data about the machinery's status, working condition, or position will be connected to a cloud-based system.

By applying Artificial Intelligence/Machine Learning /Deep Learning/ Matlab /Simulink based analytics and computation, and using the data acquired by the platform, smart predictive maintenance is achieved via cognitive digital twin. The Digital Twin, will visualize maintenance predictions real-time, and notify personnel with current condition of the machinery, abnormalities and alarms.

IV. Delivery reliability (DR)

Delivery reliability (DR) is a term that defines the number of deliveries to customers that are regarded error-free on the part of the vendor or shipper in relation to the total number of deliveries that occur within a specified period of time.

common Information and Communication Technology (ICT) techniques such as route optimization and Machine Learning (ML), can help delivery retailers optimize their systems.

Furthermore, they will minimize the dependability of trip time in metropolitan places where congestion and space limit the entrance of larger vehicles such as trucks [17]. Furthermore, employing an Electric Scooter (ES) reduces the overall carbon footprint of food delivery. The goal of this research is to reduce delivery delays while also improving overall delivery efficiency. As mentioned in [18]-[21], ICTs can be deployed to monitor real-time road contexts (e.g. Vehicles, traffic jams, weather, construction) in order to support optimal routing. Similar approaches can be utilized to shorten delivery trip time. As a result, tracking delivery scooters might considerably improve their route planning.

A DMS prototype is made up of five core mechanisms.
as depicted in Figure 4:

- a communication system, enabling DMS to interact with others and to collect information
- a ML algorithm, using historical data to predict different information
- a sharing algorithm, determining sharing possibilities
- a route algorithm, computing optimal delivery routes
- a view system, allowing managers to consult the overall system status (incoming orders and prediction, past as well as on-going deliveries).

An Android smartphone serves as a bridge between the driver/ES and the DMS. An application has been created to facilitate such communications as well as to collect Controller Area Network (CAN) data.

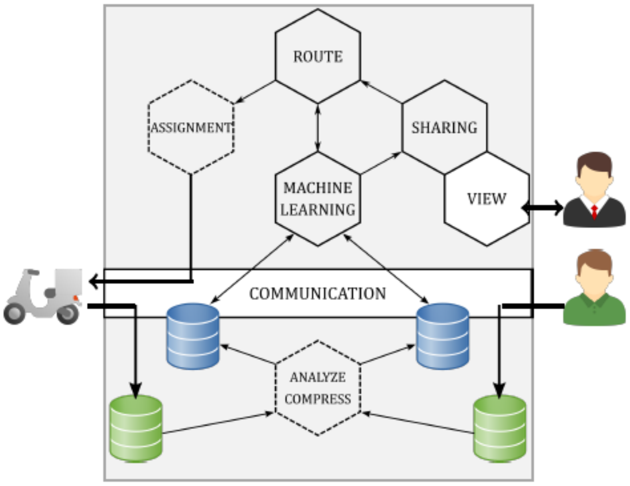

Fig.4. Illustration of the Delivery Management System prototype [19]

The HTTP protocol with REST APIs is used for communication between the DMS and the Android application over Wi-Fi or cellular networks. As a result, drivers can obtain computed route information from the DMS via the application interface. During delivery, the gadget collects information about the ES, such as current speed and acceleration state. It is crucial to establish the trip time per road segment by using a real-time monitoring system rather than an event-based one. Therefore, in our custom monitoring system, every second, the average state of each monitored data is stored by the application. The real-time position is given by the built-in drivers and information regarding the connection status:

- Bluetooth, for the communication with the ES
- Wi-Fi and Cellular networks, for the communication with the DMS
- The DMS availability. It also displays the reception state of CAN data as well as the transmission status of monitoring packets. Finally, the map at the bottom shows the motorist the optimal path that has been calculated.

The monitored data obtained from ESs is used at various times. When automobiles are "on delivery" in the first phase, their data is kept in a "temporary" Database (DB) (represented in green in the Figure 4). The DMS analyzes this data in "real-time" to detect any delays in delivery and, if possible, establish other routes. When a delivery is done, the raw data from the temporary DB will be inspected further before being compressed and saved in a "permanent" DB in a second step (illustrated in blue in the Figure 4). In our prototype, we utilize a compression comparable to the one used in the video "image to image prediction." In fact, the algorithm will choose a series of times for each delivery. All monitoring data will be saved for these instances. However, only the difference between two monitored moments will be saved for the information in between. This method allows for a reduction in the amount of data retained while keeping the same precision. Orders information are stored in the same way. Orders that have not yet been delivered are recorded in a temporary database, while fulfilled orders are saved in a permanent database. The ML algorithm will use data from the two permanent DBs to estimate both incoming food orders and travel times for different road segments at different times. A time-based machine learning algorithm.

This prototype's sharing view is shown in Figure 5. It shows a visual representation of some of the orders that have been received, as well as their status. Their connection to delivery routes the algorithm for sharing uses both the order position and the expected value at the same time to assess such opportunities for sharing, use the delivery time. The Figure 5: At any point in time, order A could share it's the order's delivery B. Readers may believe that the order is incorrect. Order E could potentially share delivery with orders C and D, but this is not the case possible. In reality, despite their close proximity, their stances are vastly different. The delivery timings are too far apart. Each time a new one appears, when an order is placed, the sharing algorithm recalculates all share percentages. in order to determine the prospects within the pending orders a perfect solution Information and data knowledge strategies are used in this project. It helps merchants to reduce delivery trip time while also increasing delivery efficiency. This method enables them to keep track of delivery vehicles and efficiently retain data.

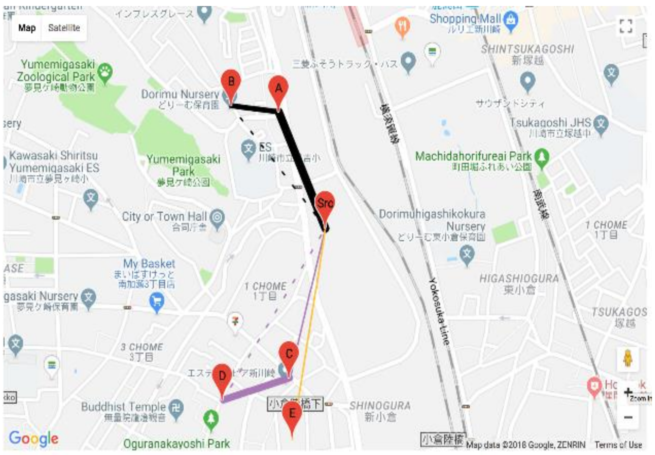

Fig. 5. Preview of the sharing view. [20]

V. IDLE TIMES

Idle time refers to the period when a workstation is starving or blocked as represented in the Fig 6. This time can only be zero when the station operates as a bottleneck. Although the production systems contain the same components, they do not work in the same way in real time [22], forcing the use of predictive control approaches to identify idle times in advance.

Furthermore, each system goes through multiple changes over its lifetime, prompting the development of an effective algorithm to predict idle times using the industry 4.0 i.e., real-time measurement of the system's current status. The following digital technologies are used to monitor the idle times which are discussed below.

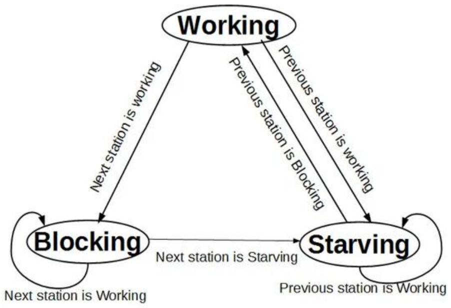

Fig 6. Representation of production systems in various states [22]

1.Mini terms; A New Paradigm for Industry 4.0:

The mini-terms can monitor in real time how long it takes to perform a sub-task on the machine element with sensor and detect deterioration that could predict a production line interruption [22]. It is also simple to set up because it usually does not require any additional installation because existing sensors may be used to produce the measurement, and all that it requires is the programming of a timer in the PLC (Programmable Logic Controller).

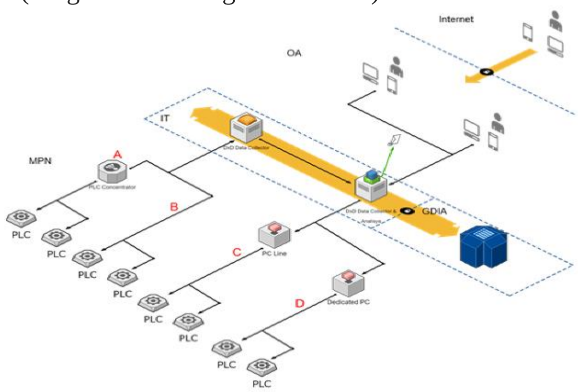

Fig 7. Layout of mini term 4.0. at Ford factories [22]

As shown in the Fig 7, mini-terms in real-time which are used at Ford factories, timers are coded into the PLCs and are transferred to a database in real-time for their analysis. When a mini-term changes significantly, an e-mail is sent to the maintenance workers, alerting on the change.

2.Prio-T:

By integrating the industry's planning system, resources, and machine operators in real time, the computerized "Interactive Prioritization Table – Prio-T" [23] displays work in progress and optimizes transparency without disrupting day-to-day. Thus, Idle time is reduced, people are more engaged, and productivity improves as a result of effective use of ICT on the production floor. Prio-T was developed by RWTH Aachen University's Laboratory for Machine Tools and Production Engineering WZL to address the tool and die industry's consistent lack of transparency and poor planning.
The interactive control table has digital capabilities and is designed specifically for tool and die companies, as illustrated in Fig 8.

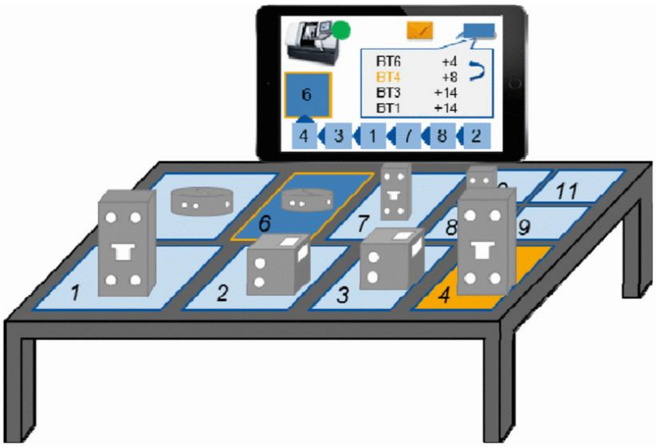

Fig 8. Interactive control table [23]

As Prio-T is integrated with digital devices such as tablet computer, as depicted in Fig 9., employees have real-time access to ERP systems and databases. Due to up-to-date and real time data, employees see a dynamic summary of current order processing on each workstation. Employees can adjust the priority of machine sequencing using tablet computers, while the impact of the rescheduling is displayed simultaneously. Employees at machines can offer simultaneous proposals. If rescheduling is required, the system displays the impact of the suggested rescheduling on the duration of the process and the adherence to deadlines. If an individual employee is unsure, additional colleagues can be consulted to help resolve the issue.

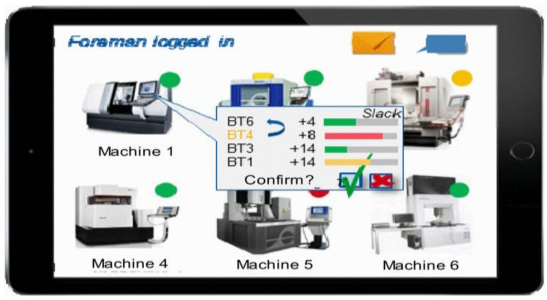

Fig 9. Planning and control tablet of the planning employee [23]

Research Idea behind Prio-T:

- Transparent and dynamic control of orders by using information and communication technology
- Component storage on the interactive prioritization table and dispatching into ERP-Systems by the respective employee
- Knowledge about processing sequences for the central planner and the machine operator
- Indication of the impact of rescheduling and the change of prioritization done by the planning employee
- More effective interaction and communication for employees

3.Advanced Planning and Scheduling (APS) system:

Advanced planning and scheduling (APS) software helps manufacturers allocate raw materials and production capacity to achieve the best balance between demand and plant capacity [24] based on available resources, personnel as shown in Fig 10. The software monitors manufacturing costs, calculates overall equipment effectiveness (OEE), and assists with material requirements planning (MRP).

With the least amount of downtime and faults possible, APS software develops efficient production schedules. GANTT charts and visual schedules can help with the entire production planning process, such as determining the best start times, the best machines to use, and the availability of employees, equipment, and subassemblies.

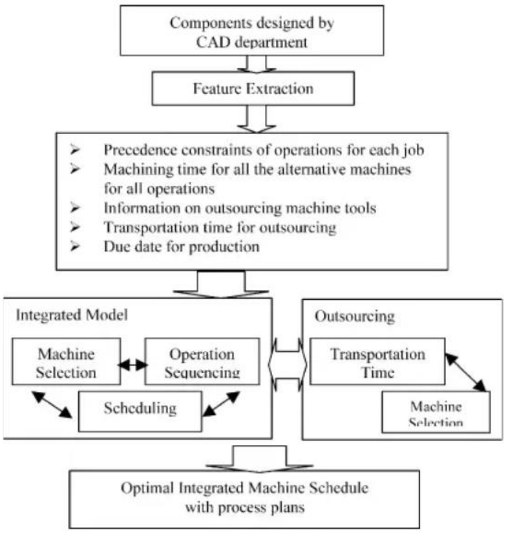

Fig 10. Schematic diagram of APS Model [24]

The planning component of the APS program is concerned with the long term, whereas the scheduling section is concerned with the immediate term.

- Planning brings together forecast and supply while allocating time intervals to each. The goal is to determine what to make or produce in each time slot, as well as how much to make and how to make it.
- Scheduling logically arranges jobs and generates a list that is disseminated to the shop floor while taking into account all constraints.

VI. VARIOUS OTHER DIGITAL TECHNOLOGIES

In the current scenarios, the digital implementation is resulting in extinct of traditional methods, bringing substantial benefits to economies that make good use of digital technologies. The following digital technologies are also be used in monitoring various key performance indicators.

1.KPI-ML, An XML:

The ISO 22400 standard specifies a technique for documenting KPIs. MESA International created the KPI-ML XML-based KPI format [25] to comply with ISO specifications, which is based on the ISO 22400-1:2014 UML model, with inclusions based on KPI exchange implementation end-user input. The KPI-ML collection of XML Schema Definitions (XSDs) describes the structure and permissible content of an XML document used in a data exchange.

The KPI-ML enhancements make use of the enhanced object model. The KPI object model is derived from the object model specified in ISO 22400-1 with the modifications.

2.Big Data:

The logistics industry has a large volume of various structured and unstructured data, which, with well-organized work, can provide companies with competitive advantages in data storage, processing, and analysis. Big data is the process of searching, analyzing, and generating new knowledge from large volumes of structured and unstructured data [26]. The use of automated logistics management systems, which optimize operations, communicate, control and reduce costs, but also save time, today's most important resource, is still decided by business entities. Additionally, these systems can be used in the planning and decision-making process by logistics companies by analyzing the data in a reasonable and valid manner.

3.Cloud Computing:

Big data requires huge and powerful storage and processing space. Cloud computing can solve this problem by providing remote data processing and storage from any location [27]. Cloud computing is a self-service way of providing software and hardware over the Internet or local network to consumers who use corresponding storage and processing services; Online access to a variety of hardware (hosts, databases, networks) and software (web versions of offline programs, varied application software requiring considerable computing resources), resources that consumers can quickly access to solve problems with minimal interaction with resource providers.

4.Blockchain:

In addition to the growing volume of digital data and its availability, there is a need for their fidelity and storage reliability. Blockchain can be applied in this way, as it is a technology that provides the illusion of database integrity by distributing data among network computers (web sites) and not storing data in one place (single website). Transparency and controllability of logistic operations along the chain of supply from the manufacturer to the end user will be ensured by the inability to destroy or modify database representations leaving no trace, encryption, and decentralized data storage with Blockchain technology. An important Blockchain feature is the instantaneous updating of information for all supply chain members at once [28].

With IBM's Blockchain platform, for example, it is possible to track truck location and status, and all chain members can see the relevant information. Manually recording supply chain transactions causes delays and increases the risk of data duplication or fraud. RFID identifications, which show data on the vehicle, driver, and cargo, enable IoT sensors to monitor truck movement and transfer this information to Blockchain. The use of IoT in such deliveries can be enhanced, for example, by the installation of humidity and temperature sensors. In the event of a sharp change in these indicators, an insurance company involved in the smart contract will report that the goods may have been damaged. This has been a boon to delivery reliability.

5.Crowd Sourcing:

Crowdsourcing is the process of gathering information, work, or expert commentary from a large number of people using the Internet, social media platforms, hosting platforms, or smartphone apps to collectively address a problem. Amazon, for example, uses crowdsourcing to guarantee two-day delivery of products purchased through its site, incorporating practically any prospective logistical carrier, including taxi businesses [29]. Crowdsourcing for logistics is an opportunity for medium-sized logistics businesses to become competitive in this environment. Another example is Cargomatic's operations. An online platform that connects local shippers with carriers with extra truck space was developed by the logistics company [30].

Consequently, Cargomatic offers web and mobile applications that help long-haul truckers grow their businesses, and helps shippers track their cargo in real time [31].

6.Internet of Things (IoT):

The internet of things, or IoT, is an interconnected network of computing devices, mechanical and digital machinery, goods, and people with unique identifiers (UIDs) and the ability to transfer data without requiring human-to-human or human-to-computer interaction.

The five layers of IoT include sensor-actor-machine level, shop floor level, factory level, company level, and supply chain level [32] as depicted in Fig 11.

There are some core technologies that play vital roles in IoT and can benefit the manufacturing industry tremendously. They are:

- Radio-Frequency Identification (RFID)
- Wireless Sensor Networks (WSNs)
- Cloud Computing and Big Data

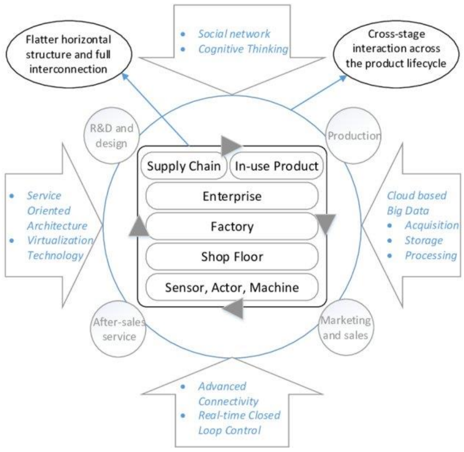

Fig 11. Impact of IoT on the manufacturing industry [32]

7.Artificial Intelligence:

The use of artificial intelligence is a powerful support for decision-making in production, as it can optimize the quality, validity and speed of the decisions made. Artificial intelligence can handle a wide array of data, enabling cloud services. Anywhere there is a need for data analysis and subsequent decision-making, that is, any place in the supply chain and in any form of logistics, artificial intelligence can be applied.

VII. CONCLUSION

The manufacturing organization faces enormous demands in terms of quality, delivery, dependability, flexibility, and cost in today's customer-focused business environment. In this regard, the importance of KPIs in production system are undeniable and irreplaceable. In this paper, it is briefly explained how KPIs are influenced through implementation of digital technologies in production systems. Digital technologies revolutionized production sectors. Before the integration of digital technologies, industries used to collect data manually and then put into excel for data analysis and to generate OEE reports. This method is both time consuming and inaccurate.

Merging all manufacturing KPI and metrics in graphical or chart form within one dashboard allows employees to get real-life data visualization, make better decisions based on these key parameters and avoid being overloaded with complex information. IoT is widely accepted as a main paradigm that can drastically transform the industries. It enables the seamless integration of a variety of production equipment with sensing, identification, processing, communication, actuation, and networking capabilities. Also, KPI-ML helps manufacturing companies worldwide to reduce the cost of developing software for exchanging KPI data between systems, plants and business units.

With the present pace of ongoing research and developments, the existing digital technologies and software’s are likely to be improved further to monitor KPIs more effectively in order to improve productivity and delivery reliability. Therefore, technologies like industrial IoT, Big Data, Machine learning, artificial intelligence are widely believed as a frontier to induce new and effective innovations to monitor KPIs.

In future developments, more useful KPIs and their supporting elements will be introduced in industries. Also, implementation of KPIs for a multi-stage production system and energy related KPIs also plays vital role in future.

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An overview on sustainable practices in a life cycle of technical systems

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***Abstract* --- Manufacturers are working hard to handle sustainability-related challenges without compromising consumer expectations or market competitiveness in the face of rising sustainability awareness and increased environmental pressure. The paper discusses sustainability in the utilization of natural resources concerning the various technical systems. The different objects of a technical system discussed below include Product, Production systems, Manufacturing technologies, Orders. Every stage of a life cycle of a technical system involves utilization of natural resources, giving opportunity to optimize and innovate different techniques and methodologies which are sustainable in its characteristics. Sustainability means efficient and responsible use of the natural resources and products. In order to understand the effect of sustainable utilization of natural resources on life cycle of technical system, diverse methods and practices discussed in the following paper which include: Life Cycle Assessment (LCA) method, Additive manufacturing (AM) technique in automotive and manufacturing Industry, Sustainable Material based approach, Sustainable Supply Chain Management (SSCM), Industry 4.0 approach and also to achieve measurement of energy efficiency, Models used to analyze energy consumption and traditional recycling using "3R" method (reduce, reuse, and recycle). The dwindling reserves of natural resources has forced the manufacturers to research and develop processes, products, methods and techniques in line with sustainability of resources. In conclusion, it was evident that the modern approach toward Sustainable resource utilization involves application of various methodologies along every stage in the life cycle of a technical system, from design, raw material acquisition to the recycling of the product or a system.**

Keywords*: *Material Selection, LCA, AM, IoT, Cyber Manufacturing, Energy Saving Technology, Technical building services, SSCM, Green Information based Manufacturing Process Modeling

I INTRODUCTION

Environmental issues such as global warming and energy usage have risen to the top of the list of the world's most pressing problems. However, there is a growing understanding of the importance of sustainable design and development of life cycle systems based on resource consumption, ecosystem safety, durability, and performance. Environmental laws have evolved as a result of rising scarcity of resources and raw materials, with potentially disastrous consequences for manufacturing. Natural resources have been significantly impacted by technical systems over their life cycle. As a result, organizations are increasingly under pressure from consumers and regulators to monitor and enhance the long-term performance of their technical systems and products [1]. Technical systems are systems that humans create and interact with, but humans are not a part of them. It is characterized by transforming inputs and outputs by way of system functions. In systems engineering, the lifecycle addresses all phases of its existence, including system design and development, production or construction, maintenance, disposal, or recycling. For example, consider an Automobile (Car) as a technical system it comprises 4 major phases viz. Engineering/design phase followed by manufacturing and distribution phase, next the largest phase is the usage of the automobile, then comes recycling of the automobile and the recycled parts can later be used in manufacturing of new products.

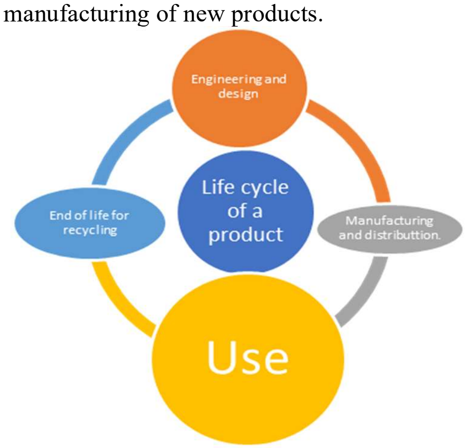

Figure 1 Life cycles of a product (Automobile)

The sustainability practice can entirely affect the life cycle of technical systems from the very beginning of design till its disposal stage. Product life cycle sustainability aims to manage product life stages to minimize their negative impact on the environment. Now Contemplating the Food Business: One of the huge drivers of additional sterilization is to propel the attainable improvement of the food store organization. Useful store network the leaders (SSCM) facilitates the possibility of viable improvement in standard creation network the board. Firms that follow SSCM track hope to achieve the expansion of the overall benefits of society, environment and economy to comprehend the somewhat long improvement targets of stock organization firms. To cultivate the middle earnestness, food firms have been progressing and updating their cutting-edge chain and sorting out an acceptable headway procedure from the source beyond what many would consider possible, to propel the overall improvement of firm amicable, regular and financial execution, influence its uplifting, and assurance food taking care of by fixing its intelligent system. Food dealing with forewarning is a fruitful technique for achieving prudent improvement of the food creation organization, since quality acceptability is the way to viable progression of the food store organization. The following Paper focuses towards understanding various methods and practices that are/were in application at different stages of the life cycle of the technical system. Both traditional and modern approaches are used to give a sense of how manufacturing has evolved over the period focusing on sustainability. As the manufacturers and industries have taken sustainability into serious account due to pressure from regulatory bodies and customers, they are giving importance to the implementation of smart factories, Internet of Things, smart material handling and Energy saving methodologies during manufacturing.

II TRADITIONAL APPROACH

A. Extraction and Processing of Raw Material

There has been an enormous progression of electronic devices worldwide over the previous two decades. Smartphones account for approximately 12% of the total e-waste deposited every year. For the manufacture of these phones, rare and precious metals like palladium, silver, tantalum, gold, and niobium are essential. These elements present only less than 0.01 percent on Earth's surface. The Environmental Literacy Council gives a list of the components in cell phones which include the phone case, screen, printed circuit board, battery, microphone and speaker, and charger [2]. While features vary by individual cell phones, this list covers the essential components of most cell phones. The following sections provide insight into the traditional approach to life cycle systems regarding the different parts of a cell phone. The history of cell phone cases dates to the 1960s, when Motorola MR20 introduced their first phone case made of leather and plastic. The skin of an animal is used in the manufacture of genuine leather. Several chemicals and toxins, including ammonia; cyanide-based dyes, formaldehyde; and lead, are used to preserve the skin, making the production unsustainable to the environment. Moreover, plastics were the other material in use and later caused pollution due to non-biodegradable accumulation on land surfaces. Moving on to the cell phone screen, the traditional ones were made of ordinary glass panes, which are a composition of sand, soda ash, and limestone. Being a major component, limestone was readily available on earth and is most often mined from quarries. The printed circuit board (PCB), considered the brain of a cell phone, consumes a more significant number of primary and rare metals for its production. For example, the Nokia 3210 model released in 1990 used primary metals like Lead, Copper, Iron, Aluminum, Tin, Cobalt, Nickel, Zinc, Chromium, and precious metals like Platinum Gold, Palladium, and Silver for its PCB [3]. The metal yttrium used in memory chips is a scarce earth element. The mining of these metals has environmental consequences, such as landscape devastation, dust contamination, and leakage of hazardous things to water bodies. The battery is the major part after PCB in the usage of metals. The battery used for Nokia 3210 model was a rechargeable Nickel-Cadmium 1250 mAh. The extraction of Nickel is more, because of its high availability whereas Cadmium is an extremely rare element that is taken out as a by-product of treating zinc, copper, and lead ores. Speakers and microphones are the next ones where the mineral source of Bastnaesite is deployed for the production of magnets. Last is the cell phone adaptor, which was made of regular plastic for covering and inside with a connection of capacitors, resistors, and rectifiers.

Mineral Commodity	Mineral source(s)	Usage of the commodity in mobile device
Germanium	Sphalerite	Battery, display, electronics and circuitry, and vibration components.
Graphite	Graphite	Battery anodes.
Indium	Sphalerite.	Liquid crystal displays
Lithium	Amblygonite, petalite, lepidolite, and spodumene	Battery cathodes.
Platinum-group metals	More than 100 different minerals	Circuitry, capacitors, and plating.
Potassium	Langbeinite, sylvite, and sylvinite	Screen glass.
Rare-earth elements	Bastnäsite, ion adsorption clays, loparite, monazite, and xenotime	LED phosphors, screens, speakers, and vibration motors.
Sand, industrial	Silica sand	Screen glass and semiconductors
Silicon	Quartz	Semiconductors
Silver	Argentite and tetrahedrite	Circuitry
Tantalum	Columbite and tantalite	Capacitors
Tin	Cassiterite	Liquid crystal displays and circuit board solder
Tungsten	Scheelite and wolframite	Vibrator

Table 1 Mineral commodities used in mobile [4].

B. Design And Development of a System

The authors paint a picture of both the complexity of environmental difficulties faced by the automotive sector and the diversity of academic approaches to a variety of themes. Term Sustainability to the manufacturer of automobiles of the last few decades meant ways to reduce emission. From the to mid-2000s visible effort was put into introducing sustainable practices from Design, Manufacturing, vehicle use to end of its life cycle, also its adoption in management practices at different levels, along different organizational forms to the response to environmental pressures. Application of sustainable practices in the design and development phase is very important, this approach was missing in past decades as the way of producing a environment friendly automobile was reducing its carbon emissions, but in modern approach it’s the integral part of sustainable car [5] .

C. Operations, Production

Additive manufacturing (AM) traditional approach towards manufacturing--The production of a three-dimensional object from a CAD model or a digital 3D model was a revolution in terms of producing and manufacturing with minimal wastage and intricate shapes. L-PBF (Laser Powder bed fusion) has historically been the most popular method for industrial application and research. Metal AM processes such as LPBF have made possible printing components generated by generative design and topology optimization, meaning the printing of parts where the structure of the internal volume can be controlled and designed as wished. Improved efficiency and overall mass reduction in order to improve performance-to weight ratio will be the motivator for metal AM for further integration with automotive components. With the rise of additive manufacturing technologies there is introduction of “functional printing” and recently “industrial printing” terminologies. The term “functional printing” refers to the enhancement of existing AM technologies to the point of being able to create fully functional printed devices as ready-made products in a single manufacturing process. This will reduce the amount of material that could be wasted compared to conventional methods of manufacturing. The concept of “industrial printing” can be understood in the context of AM processes as being an integrated asset of the manufacturing process chain and is aimed to contribute to the production processes by adding functionality to the fabricated part or enhancing existing ones; more exciting and new approaches of AM are discussed later in this paper [6].

D. Recycling and Disposal

The “products processing” System: Natural resources are critical determinants of human life quality, and each country should keep a close eye on them not just for its own sake, but also for the sake of the entire Planet. People are mostly concerned with main resources at the moment. (Water, oil, coal, and natural gas, for example) Secondary, on the other hand, equally crucial are resources. “Sustainable” is in high demand. “Development,” a “circular economy,” and an “eco-economic system,” are some of the terms used that have been promoted all across the world. As a result, industrial firms and various technical systems have been focusing the recovery using the “3R” method (reduce, reuse, and recycle) for past few decades. The products’ processing system, Recycling resources is not only good for the environment, but it is also good for business, and also encourages technical advancement [7].

III MODERN APPROACH

A. Extraction and Processing of Raw Material

Considering sustainability, the cell phone industry moved to use more green materials on material selection for each component of the cell phone. Nowadays, Silicon, leather, and Plastics (polyurethane, polycarbonate) are the common materials used to make phone cases. Regarding availability, Silicon is the second-most abundant element on Earth after oxygen which is most often found as silicate minerals after being combined with oxygen and other elements. During combustion, Silicone produces no harmful bi-products, giving it an edge in our more earth-conscious world. Plastic phone cases are normally made of polymers like polycarbonate or thermoplastic polyurethane using chemical reactions. Polyurethanes are durable and can ensure an extension in many product's lifetimes compared with no coating. By this, it can save the natural resources from more and more extractions.

Figure 2 Silicon phone case [8].

Figure 3 Thermoplastic polyurethane[9].

Polycarbonate is plastic and can be environmentally damaging if not supervised or appropriately recycled**.** However, its advantages are indeed and provide efficient recycling opportunities [10]. Using sustainable materials in the conceptual phase changed the development, production, and disposal or recycling phase of cell phone cases, causing low to nil pollutants into the atmosphere. As an alternative to traditional glass panes, the glass in today's cell phone screens is mostly aluminosilicate glass (Gorilla glass) which can resist shattering and scratching when dropped onto a hard surface. In technical as aluminosilicate glass, Gorilla Glass is a composition of an oxide of aluminum and silicon, along with sodium ions.

Figure 4 Gorilla glass Victus introduced in July 2020, which can prevent damage up to 1.6 m height fall [11].

Considering the case of the United States, only 0.34 million tons of e-waste are sent for recycling out of 1.36-1.72 million metric tons of wastes disposed to landfills. In addition, approximately 300,000 cell phones are thrown as trash making LCD recycling more challenging [12]. Because of not recycling them properly before disposing, many health issues arose prompting for a more sustainable technique for implementation. The change of using regular glass to aluminosilicate glass made the production more sustainable, more life, and less waste, which turned into a positive aspect towards sustainability. Since PCB of a cell phone has precious and rare metals, the consideration of sustainable practices will be more in this area to reduce the mining and focus on more reusability.

Figure 5 PCB of iPhone 13 pro [13].

Every year, it is estimated that roughly 100 million mobile phones are discarded [14]. If one million of these phones are recycled and not put into landfills, the manufacturer can recover 75 lbs. of gold, 33 lbs. of palladium, 772 lbs. of silver, and over 35,000 lbs copper [14]. During the recycling phase of PCB, many techniques fail in recovering certain ceramic parts which can lead to negative environmental consequences later. For ensuring a high recycling rate, harmful materials are phased out from the PCB manufacturing process, leaving only metals parts that can be easily recovered and environmentally friendly. Considering sustainability in the energy section, most modern mobile devices use lithium-ion (Li-ion) batteries, consisting of two main parts: a pair of electrodes and the electrolyte between them. Spodumene and subsurface brines are the sources of lithium used in cathodes of lithium-ion batteries [15]. Furthermore, due to its electrical and thermal conductivity, graphite is employed for the anodes of lithium-ion batteries. Spodumene is nearly exclusively found in granite pegmatites that are high in lithium. Quartz, microcline, albite, muscovite, lepidolite, tourmaline, and beryl are all rare earth minerals [16].

Figure 6 Battery of iPhone 13 pro [17].

The lithium-ion battery industry's growth is set on recycling innovation, ensuring that these batteries' production is as environmentally friendly as possible. Microphones and speakers require very little power to operate and can easily be powered by the cell phone's battery. Bastnäsite is a source of rare earth elements used to make magnets for speaker microphones. Since its availability is rare, technical measures are used in the recycling phase to ensure sustainability. Instead of regular plastics, degradable plastic coverings are used in cell phone adaptors nowadays to ensure sustainability during disposal. Inside electrical components are recycled to reduce the mining process to extract minerals used in electrical components. Current strategy for food handling and conservation has assumed control over the business; innovative progression and modern insurgencies keeps the healthy benefit, taste and nature of food longer and better than the previous years' techniques. Probably the most encouraging cycles that can oblige the current day food interest as investigated by [18] are: Pulse Electric Fields (PEF), High Hydrostatic Pressure (HHP), others are; Irradiation which includes openness of food item to ionizing radiations or electron shafts or beams to kill microbes, it is likewise used to defer organic products aging and vegetables growing [19], Canning and Bottling which includes items stuffed and fixed in the holder under controlled temperatures and Refrigeration Systems.

B. Design And Development of a System & (Extraction and Processing of Raw Material) (Product Engineering)

During the design phase and subsequent stages of the technical systems life cycle, designers and organizations have access to a variety of sustainability performance evaluation methods. Life cycle assessment and material flow analysis are two prominent examples. Exergy analysis, energy analysis, and energy analysis are also some of the most frequently used sustainability performance evaluation methods. [20].

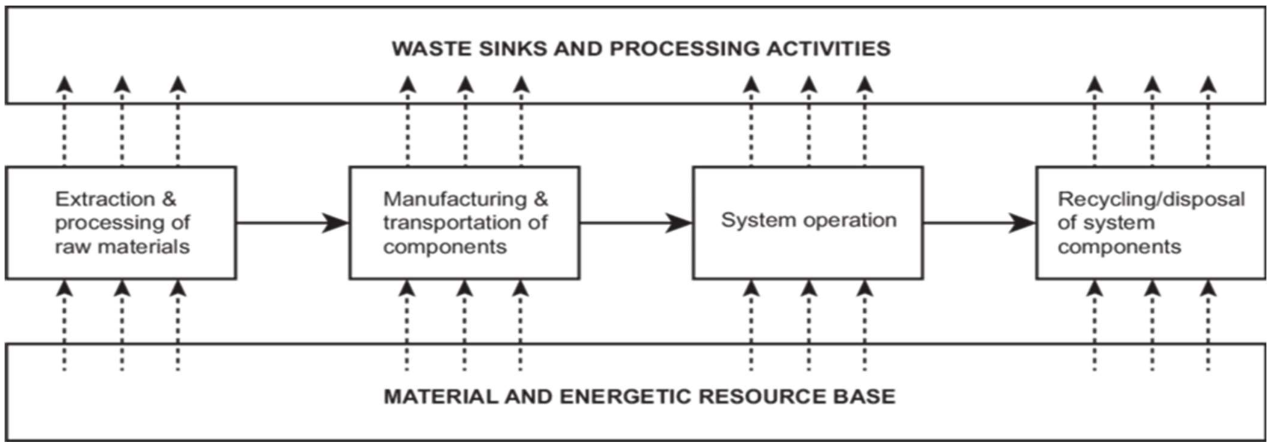

Figure 7 The technical system life cycle [20].

Design phase is one of the key areas to look at for significant improvements. And One of the most important parts of the product design process is material selection, which has a significant impact on the development of a technical system with a sustainable outlook [21].There is a need to filter materials based on sustainability considerations of natural resources and then perform LCA in order to determine the changes of the technical system in question. TU of Delft has developed a software IDE mat which helps in selection of low impact materials. They have created a database of not just physical and mechanical but also the environmental characteristics of materials. And looking at this on a bigger scale, we can identify the phase that is performing the worst (in terms of sustainability) and concentrate our efforts there. LCA is also being applied to Car tires. The authors have used LCA to assess the environmental impact of tires. Life cycle of tires include raw materials acquisition, production/manufacturing, usage and ending with end-of-life management. There are legislations being put forth to reduce the effect of tires on the environment, to achieve a particular degree of automobile tire recovery, legislation imposes waste and product management regulations, as well as deposit fees, which producers and importers must comply with or face penalty.

An ecological energy analysis of the life cycle of a car tire was used to determine the locations with the most damaging environmental impact. According to studies, the use stage has the greatest number of environmental repercussions. Furthermore, recycling automobile tires lessens their negative influence at all stages of their life cycle to a minor extent. To reduce tire effect, more efficient recycling processes must be introduced, allowing for the most efficient use of materials and components from automobile tires while also reducing energy consumption to avoid further environmental burdens. The above information on harmful effects of car tires makes it very important for the engineers to work on developing efficient ways of recycling the tire which in turn affect the life cycle of the technical system(automotive). The proper use of natural resources such as rubber and clean disposal or reduction of harmful substances from the tire are a way for a sustainable future [22]. Our analysis also revealed that the factory of the future would need to adjust quickly to shifting external demands while pursuing a better level of sustainability. Future manufacturing will need to consider all three elements of sustainability - economy, ecology, and society - more than it does now. Manufacturing profitability must be increased from an economic standpoint. From an ecological standpoint, production's environmental consequences should be mitigated, with the factory having a beneficial impact on its immediate surroundings. From a social standpoint, the factory should be a gathering place for people, with a focus on collaborative learning and human capacity development [23]. The Factories of the future will consist of the following aspects:

Symbiotic Flows & Urban Integration: The factory of the future must concentrate on the metabolic process that allows materials to remain as resources and increase in value over time, resulting in a positive ecological and economic relationship. It is, however, insufficient as a long-term solution because it will only serve as a damage management plan. [23].

Adaptable Factory Elements: The ability to successfully cope with the emerging trend of personalized products, as well as the strong linkage of material and energy flows with external infrastructure, necessitates an appropriate and highly flexible physical factory infrastructure, including its building shell, technical building services (TBS), and production system. Modularity, Scalability, Universality, Compatibility and Mobility are the five principles which enables the system to transform at the factory level. [23].

Production Cloud and Cyber Physical Systems: The gathering, consolidation, and processing of information on a higher level will be sensible, even though choices will be decentralized by independent agents, since information technology will take over all manufacturing levels, including a broad application of sensors on the shop floor level. A decentralized data pool, dubbed a "production cloud," would be created, storing massive amounts of data produced in the factory and gathering and analyzing all data from the production system. This concept is intertwined with the concept of the Internet of Things (IoT). Data cloud has various benefits, including a high level of transparency through inbuilt monitoring and control mechanisms, as well as future enhancement potential [23].

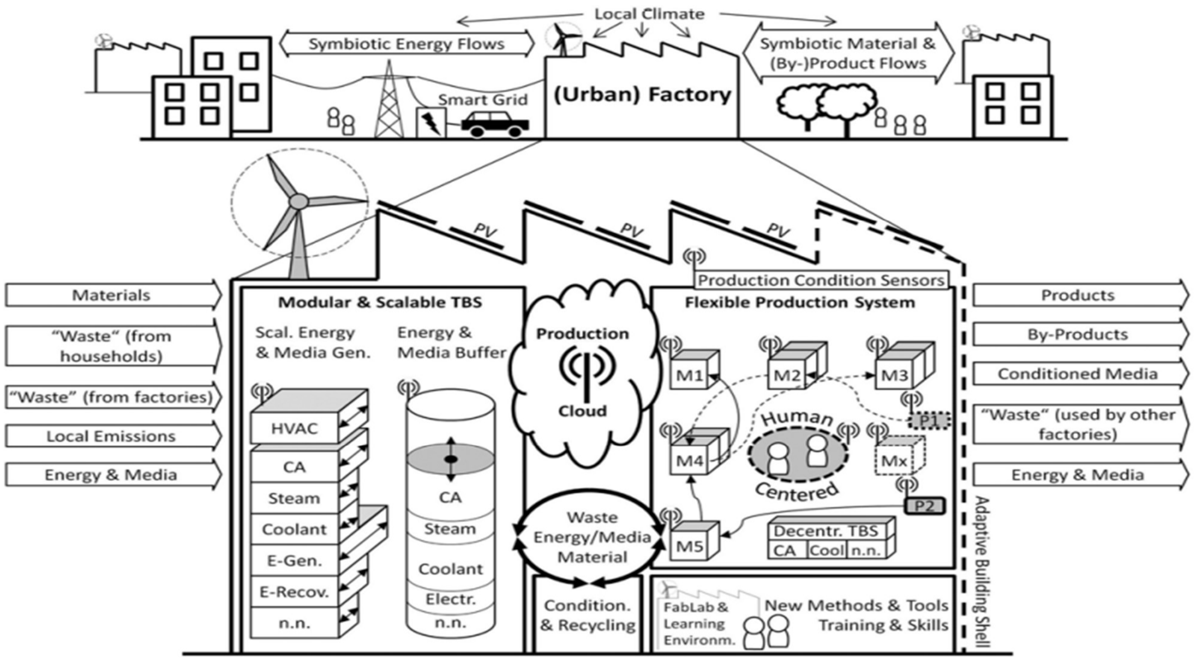

Figure 8 Holistic understanding of Factory of the future [23].

Another holistic approach to achieve sustainability in manufacturing industries is by moving towards green manufacturing and modeling a system as required to adapt in the current existing models one such model is **Green Information based Manufacturing Process Modeling (GMPM)** where the purpose of using GMPM is to extract basic functional requirements from manufacturing processes. A standardized and suitable **Manufacturing Execution System (MES)** functions for each manufacturing firm can be visualized by mapping with ISA-95 standard. Green data on industrial processes is adapted in part from the Green-BOM idea (Bill of Material). It has been recommended to incorporate numerous variables impacting the environment and human health in addition to the definition of an existing BOM. Assist manufacturing businesses in improving their manufacturing sustainability by providing support for functions that are focused on sustainability. [24]. **Cybermanufacturing** also has a great contribution in attaining sustainability and through research we found that, through proper designing of system sustainability can be achieved. One such model proposed was **Cybermanufacturing system (CMS),** where in the proposed architecture of CMS, at both ends, the physical provider layer and user layer shows more adaptability in contrast to less rigidity in internal components and structure. The intermediate layer, the core services layer, however, remains stable, and the only dynamic behavior in structure architecture is the addition or removal of storage or computational power. Additional changes arise from intermediary or supporting components or layers that can be introduced to the structure based on business demands, user requirements, job specification, or research importance, in addition to the dynamic behaviors generated by adaptability. This suggested design decodes CMS's core process and shows how it differs from other manufacturing systems. As a result, manufacturing systems may be built using this design, and CMS expects them to give a fair answer to every industrial activity. [25]

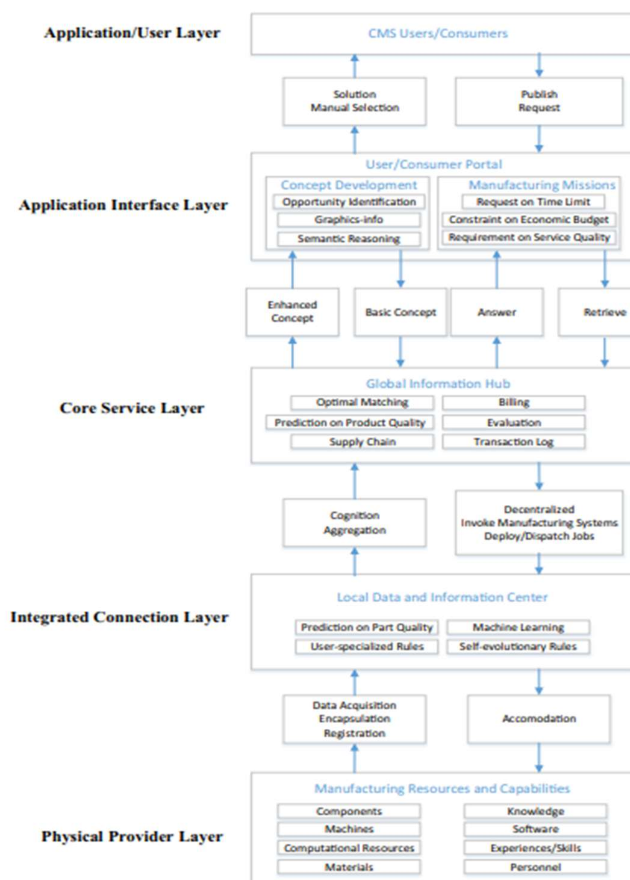

Figure 9 CMS hierarchical architecture [25].

Food industry: The plan and advancement of reasonable techniques and methods are presently common and of high significance in the food business [26]. The food business, as most others, are extremely aggressive, and each association or party included, needs to acquire the upper hand [27]. Most food organizations currently need to participate in economical creation and diminish carbon impression to remain cutthroat in the business [26].In food producing, ordinary food handling and safeguarding techniques like singing, drying, cellaring, salting, maturation and so on have not been supportable enough contrasted with the advanced strategies. Research has brought up that these customary strategies utilize enormous volumes of water, energy, solvents, and toward the end, will likewise create risky waste substances [26]. In the interim, the new creative procedures include less utilization of energy, water, and time, which upholds maintainability.

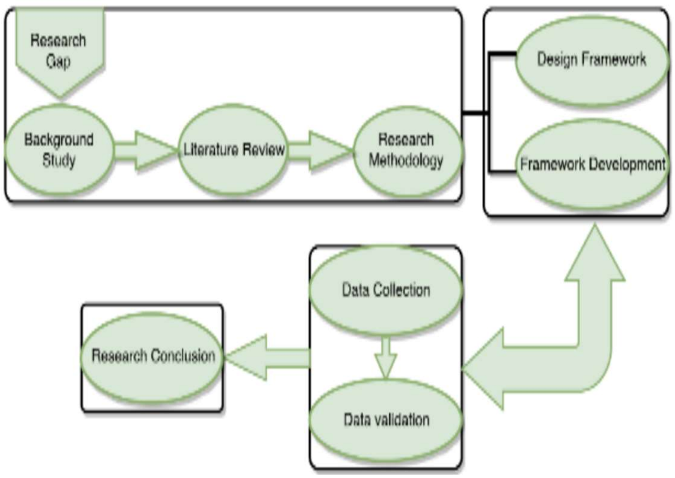

Figure 10 A proposed research framework [28].

C. Manufacturing/production.

Considering sustainable practices being used in the manufacturing phase we get the novel technique of Additive Manufacturing (AM), more widely known as 3-D printing. Review of the research paper gives insight into how AM could be used as a major driver in transitioning from conventional manufacturing processes to green and electric mode of production. Electric vehicles are getting popular with every passing day, every major automobile manufacturer is now offering fully electric alternatives to the traditional one. This is in line with major sustainability trends in today's globe, which include a decrease in the use of fossil fuels and other fossil fuel-dependent technology. Additive manufacturing-based technologies provide the automotive sector with wider opportunities compared to earlier days, 3-D parts not only enable complex optimize design but also promote material efficiency. Traditional Metal based additive manufacturing technologies such as Laser Powder bed fusion (L-PBF), Electron Beam Melting (EBM) etc. (Discussed in earlier section under traditional approach) [6].New opportunities in AM, Inkjet technology (refer figure 11) used to produce flexible Touch sensitive sensors, vacuum foaming of these sensors can be mapped onto different geometries, also can be used to integrate sensing functionalities to complex geometries inside and /or outside a vehicle, production of hydrogen fuel cell components (sustainable fuel source), polymer organic light emitting diode (PLED) is its latest application. Then also the potential for AM as an enabling technology for electric transition. Overall weight of the electric vehicle can be reduced by using Am over conventional production methods, giving more miles per charge along with sustainability of production and supply. Manufacturing of Bio-inspired Honeycomb structures, that offers several benefits along the supply chain. One of the major technical opportunities are by optimizing design to include cooling channels, which are very difficult to achieve in traditional metal forming processes. Whereas these confined changes appear to be or maybe immaterial at the first glance, they come with expansive results in the event that connected on a wide premise. Diminishing the complexity of the global supply chain and, basically, of the company's worldwide carbon impression (energy savings) are a coordinate result of a large-scale AM production of complex structures on location [6]. Also, the Role of OEM (Original Equipment Manufacturers) in sustainability is discussed by the author using Porter's Five Forces to explain original development and the future progress of the technology, and also gives insight into potential drivers of sustainability in the automotive industry focusing on the OEM's, view and also talks about the automotive industry with regards to sustainability from OEM, customer, supplier's point of view. From **customer** point of the OEM needs to few requirements ``Base" (certain level of emissions (such as CO2, NOx) or safety and security requirements) "To Be" (customers' expectations in terms of common achievements within the field of competition or vehicle segments) "Differentiation" (monetary benefits for the customer) the customers expectation to work in the direction of sustainability. Considering **competition**, the companies are now focusing on electric vehicles and battery technologies. What technology will be relevant at what time is the question which the **suppliers** need to keep in mind while doing research. In order for OEM to move into the direction of a holistic sustainable approach the suppliers are pushed into the direction of ISO. Last but not the least, the **substitute products and services**, viz public transport, carpooling etc. which would produce less emission per person are major reasons for automotive manufacturers to innovate more sustainable products and processes to be affordable options to customers and environmental regulation by the governments. [29]

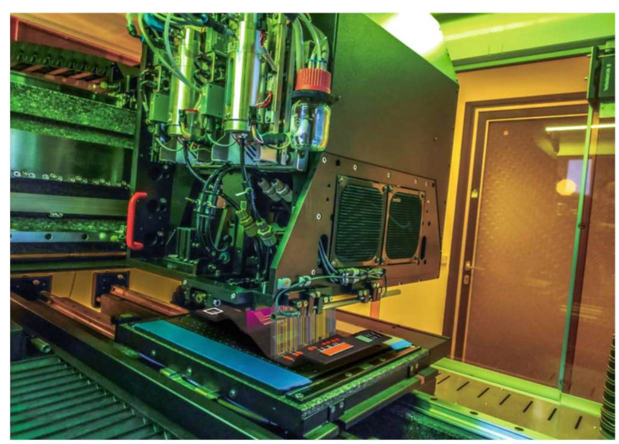

Figure 11 Illustration of an on-demand multi-material inkjet printing platform with fully functional3D printed product [6]

As manufacturers are focused on energy saving methods, the following manuscripts provide few methods as mentioned below. Manufacturing is strongly linked to natural resources, and industrial enterprises are major consumers of basic energy sources. The energy consumption of manufacturing has come to the attention of industrial enterprises as a result of rising energy prices, ecological importance, and legal pressure. As a result, these businesses must now establish an energy consumption model, assess energy efficiency, and anticipate energy usage [30]. **Measurement of energy efficiency** in industries may achieve a feasible energy reduction of at least 30% of the whole energy savings potential by applying solely procedural and behavioural improvements. Only 43% of manufacturers' energy inputs go to process tasks, while the other 57% is wasted or diverted from the planned process activities. Production process chains, energy analysis of production, energy analysis of technical building services, load profile and energy costs/energy supply contract analysis, and integrated simulation and evaluation of production systems have all been developed as part of a holistic five-step approach to increasing energy efficiency. **System and simulation approaches** focus on economic and environmental goals. The research focuses on optimizing the production chain with the goal of achieving the highest possible electric energy efficiency through simulation. A manufacturing plant is described as a dynamic complex control system with inputs, outputs, and internal variables such as energy, material, local climate, and waste heat and material, among other considerations, using the suggested subsystems. Using a simulation model, the paper recommended a five-step approach: (1) Production process chain analysis; (2) Production and equipment energy analysis; (3) Energy analysis of technical building services; (4) Load profile and energy cost/energy supply contract analysis; (5) Integrated simulation and evaluation of the production system. The two most representative concentrating initiatives for constructing future intelligent power networks are **Grid Wise** and **Smart Grid**. The GridWiseTM testbed uses digital technology, dynamic pricing, and consumer-driven control to perform decentralized power usage coordination, resulting in greater dependability, capacity utilization, and customer satisfaction. In addition, the Super Smart Grid strategy, which combines decentralized and wide-area power generation. Grid-connected modes of operation at distribution voltage levels are examined and analyses [30]. Innovation is a thought distinguished or seen as new by an individual or gathering of people as an answer or improvement to social or innovative issues or changes [31]. Development can be supposed to be the execution of novel thoughts subsequent to joining assets and useful powers apparent through inventive remembering to take care of a particular issue or enhance what is happening [32]. Advancement inside the food business has turned into a thing of interest due to its significance [31]. This advancement is a fundamental cycle in the food business that could carry improvement to sanitation, food security just as work on the triple primary concern of supportability, the, for example social, monetary and ecological circumstance inside the business' production network. Development procedure ought to be considered all through the whole inventory network in the food business for development; it should all begin from the reason behind collect or natural substance obtaining, handling or fabricating and all through the whole appropriation network till it gets to the last customer. A few specialists have presumed that "Development in the food business joins mechanical advancement with social and social development to additionally further develop purchaser items and administrations" [31]. In any case, food industry advancements and procedure ought to be underscored for maintainability particularly at this time of arranged Sustainable Development Goal for natural and human assurance. There ought to be an appropriate appraisal of the natural part of food production and this will, thus, fortify the social and monetary place of the business. Food industry development and methodology ought not exclusively be coordinated completely at innovation changes in the food business, however the social and ecological changes likewise should be considered to guarantee creation of food that fulfils the healthful, individual and social necessities of the buyers [31]. In any food business and the food business as a rule, studies have distinguished development as one of the essential drivers for development and the fundamental point of this is to ensure that great and quality food varieties are delivered in a productive, successful and supportable way [32]. Utilization of new innovation in the food producing production network could uphold manageable practices, and this could go far to help in accomplishing the required manageability inside the food business. Execution of the most recent innovation (industry 4.0) inside food assembling will be of high advantage to the food business particularly for manageability purposes [32] , and this will without a doubt uphold the economical creation which each venture is endeavouring to accomplish. The utilization of this cutting-edge innovation could go quite far to address a great deal of the recognized issues like food handling, food security control, perishability, cutthroat strain, trouble sought after forecasts and so forth inside the food fabricating settings. The advanced innovation assimilated in the most recent industry 4.0 innovation in resolving these issues. For example, Internet of Things (IoT) is relevant in following of requests and other Transportation Management Systems which guarantees food handling, advances new item improvement through shopper's criticism, span correspondence gas to help the Just-In-Sequence and Just-In-Time process expected to meet client' prompt necessities [33] [34]. Large information is helpful, popular and supply expectations and consequently aids better creation plans which controls food squanders [34]. Mechanization, keen advanced mechanics and added substance fabricating advance better usefulness and diminish the danger of both food handling and occurrences related with wellbeing and security [35]. Following and constant checking of items utilizing some trend setting innovation like sensors, Radio Frequency Identification labels, scanner tags and so on will be sensibly great in tending to the majority of the related issues inside food assembling and production network conditions [33]. These advances and a lot more could diminish squanders and superfluous development of items with better methods for correspondence and in this way decreasing GHG emanation and carbon footprint [32].

D. Operations (Servicing and Maintenance)

CMS have shown few unique functions which benefit in reducing labour, damage control and parallelly reducing cost of handling machinery. Real-time acquisition, big data analytics, essential information elicitation, behaviour learning, prediction, and physical actuation support the five roles. Self-monitoring entails continuously monitoring and integrating the condition of production components, as well as reacting quickly to any changes. Due to the deployment of sensors and the usage of the Internet of things and cyber physical systems, the conditions of production components and accommodations are continually monitored with little or no delay. Situations identified by sensors in the physical manufacturing production line, such as the failure of one component, stop the production line where the failure component engages, preventing the accumulation or even congestion of work-in-process inventories in the line. **Self-awareness** is the ability to determine whether or not to switch the operating modes of machine units, based on user-defined parameters and self-evolving rules. The integrated connection layer executes this operation. To learn the behaviour and identify any impending working pattern, self-awareness employs a user-defined supervisory mechanism. **Self-prediction** entails intelligently learning the probable behaviours and working patterns of manufacturing components, as well as intelligently scheduling assignments to ensure product quality, completion time, and machine tool health. It finds its application mainly in integrated connection layers and core service layers. Self-optimization aims to grade the performance of manufacturing components based on task-specific criteria, allowing for the most appropriate selection and matching. The matching mechanism prevents underqualified resources and capabilities from wasting opportunities and materials, as well as overqualified resources and capabilities from consuming more investment and energy than is required. **Self-configuration** is the process of creating a list of client requests in the cyber manufacturing system with varying priorities and assigning those wants to unused and temporarily idle manufacturing components, as well as persons and systematic know-hows, as services. A list of waiting jobs, particularly finishing operations like hand assembly, inspection, and packing, will be intelligently distributed to physical manufacturing units in the physical provider layer in the core service layer. The utilization of these jobs is boosted by configuring them to existing but unused or temporarily idle production equipment, as well as the related staff and know-hows, as configurative possibilities. [36]

		Functions				
		Self monitoring	Self awareness	Self prediction	Self optimization	Self configuration
Layers	Application/user layer					
	Application interface layer					
	Core service layer			√	√	√
	Integrated connection layer		√	√		
	Physical provider layer	√				√

Table 2 Implementation layers of CMS functions [36].

E. Recycling and Disposal

Sustainable food handling is characterized as the "specialized cycle which includes the decrease of water utilization, energy and furthermore permits the reuse of results while guaranteeing a protected and top-notch food creation" [26]. The exploration by an examination in 2016 inferred that the affirmation of worldwide food security requires the coordination of inventory network accomplices in each phase of food creation. Subsequently, supportability in food handling and assembling should begin from the obtaining of the unrefined substances for creation; this makes reasonable farming a basic angle to examine while discussing maintainable practices in food handling and assembling. This feasible farming, similar to other people, should take into consideration the monetary, social, and natural variables. It was once assessed that farming creation contributes around half discharge ozone depleting substance emanation inside the food inventory network organization. [37] In the meantime, perhaps the most effective way to concoct best maintainability methodology could rely upon the variables such as energy savings, water conservation, recyclable materials usage, reduced fertilizer usage, reduction in greenhouse gas emission, waste reduction, reduced transportation, water recycling; these elements impact the reasonable food production. These elements could be basic markers that should be viewed as when arranging great manageability inside food production. [38]

IV CONCLUSION

Sustainability is foremost in each assembling and administration association at this essential time of environmental change. The purpose of this research is to create a comprehensive, multi-faceted description of CMS, Industry 4.0, Factory cloud, GMPM and other models are relatively new manufacturing and energy saving systems, from the perspectives of initial definition, architecture, uniqueness, functionality, and simulation analysis. By combining all manufacturing data, these sustainable manufacturing techniques provide a superior choice for addressing bottleneck issues in material and energy usage, as well as increasing production efficiency and pricing strategy. It is really smart as various guidelines and regulations to control organization's footprints are jumping up to support reception furthermore viable utilization of reasonable practices and with social awareness in customers making the manufacturers and various players in the supply chain to push their boundaries and adopt innovative sustainable techniques to be in the market. Compared to traditional approaches for sustainability along the life cycle of technical system (where manufacturing and to some extent recycling phases were focused), there has been holistic focus on every stage of life cycle in modern approach. To a larger extent the current state-of-the-art technologies AM and vertical integrated technologies like cyber manufacturing, Industry 4.0 and many more techniques are the process of integration of sustainability with manufacturing. Overall, the above-mentioned methodologies, technologies, techniques and processes would lead to reduce the dependency on the natural resources in particular. The future prospects in the field of sustainable manufacturing could be integration of current systems for more efficiency also in all industrial sectors, new energy-saving and harvesting technologies have emerged as a crucial driver of future economic growth. This research provides the first exploratory insights into the long-term viability and benefits analysis of manufacturing, and it serves as a good foundation for future research in this field.

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Sustainability of natural resources and its impact on Engineering practices

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***Abstract*—Scarcity in availability of natural resources has a tremendous impact on the lifestyle and practices of human society. This is not any different to the functioning of Engineering and relatable organization. Sustainability and Quality has become a common goal for various specialist fields that are part of Design and Operational process in an organization. Attaining these objectives is thought to be the ultimate purpose of integrated design. In this paper, survey of existing research activity implementing sustainability across engineering process and its impact were noted and combined to give an overall understanding of the topic. This paper discusses on proposed new Engineering Design problem solving method considering sustainability of natural resources, Sustainability engineering toolbox like Life Cycle Assessment (LCA) and Quality Function Deployment (QFD) utilized as a method for Sustainability Function Deployment (SFD) that is incorporated in system level design for sustainability. This paper also includes example study previously done to show the impact of sustainability in Space industry and Cement industry.**

Keywords—Sustainability of natural resources, Impact on engineering practices, Existing research activity, Quality function deployment, Sustainability engineering toolbox, Engineering problem solving method

I. INTRODUCTION

The term sustainability was interpreted in a different way over the period of time. Until mid-twentieth century, sustainability was defined as "capable of being sustained (Collins English Dictionary). It was changed later to "able to continue over a period of time" (Cambridge Dictionary). Sustainability can be achieved through 2 strategies [1] namely, Respect for the ecosystem and focus on time factor especially the link between past, present and future. Sustainable design approach is the combination of Sustainable development and Quality Design approach which was explained by in a journal published by Thiébat, F [2] which is represented as image below

Fig 1: Sustainable Design approach (Thiébat,2013)

Interaction between the Environment and Economy paves way for the concept of circular economy which shows the divide of societal resources between alternative uses. One of the goals of economic systems is to achieve this.

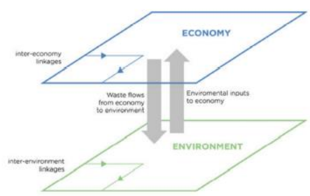

Fig 2: Interaction between the environment and the economic system (re-elaboration of the image, Pearce 1990) [1]

As shown in the Fig 2, The figure's upper section represents Supply and Demand, which includes energy sources, fisheries, land, and the environment's capacity to receive waste products.

The environment is represented on the lower end. The Inter economic linkage can be understood with an example of Steel demand affecting a Car production and Inter-environment linkages can be understood with an example of Soil property affected by the water content. This interlinkage between 2 layers drives the Environment economies. For long-term sustainability, the rate of resource extraction must be less than or equal to a rate of resource replenishment. The rate of extraction of non-renewable resources should be carefully regulated since it has a greater impact. Similar to the concept of circular economy, circular approach to design is adapted in order to create a linkage between the environment and the designed product. The term "Cradle to Cradle" was coined by German scientist Michael Braungart and American architect Bill McDonough to describe a technique that recognizes the proper disposal of waste and productive process of nature's biological metabolism as a model for developing a "Technical metabolism" flow of industrial materials [1]. Designers all over the world are trying to implement a circular approach to designing process.

II. EXISTING RESEARCH TOPICS

A. New Engineering Design problem solving method considering sustainability of natural resources

This concept was initially referred in the journal [3] and the same as been interpreted here in this paper.

A global concern regarding the environmental impact of industrial processes and the sustainability of products have pushed design engineers to make genuine efforts to be more environmentally and ethically responsible [4]. [5] considers sustainable natural resources as one of the key requirements for engineering sustainability and provides the idea of reusing the waste from engineering processes so that the net resources would be as minimum as possible. This links with a concept 'Lean Engineering' which as an engineering management philosophy focuses in reducing waste along the value adding chain of engineering [6]

Considering sustainability of natural resources in the requirements list of an engineering design process greatly affect the overall design process [4]. This paper says that sustainability seems somehow incompatible with the conventional design approaches, so a new methodology of design is required that considers the sustainability and environmental impact throughout all the phases of engineering design.

A new methodology of solving an engineering design problem is given by [7] in regards to considering environmental aspects to a design. It gives seven different phases as shown in the figure below for engineering design process, which explicitly considers sustainability aspects.

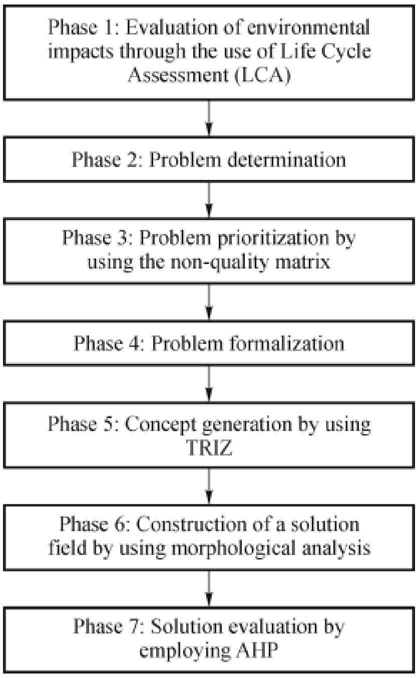

Fig 3: Flowchart of eco-innovative design process [7]

Phase 1 of the design process employs the Life Cycle Assessment (LCA) approach, which is often regarded as the most accurate method for calculating environmental consequences [8].Phase 3 employs a non-quality matrix, a two-dimensional tool that groups non-quality cases, i.e., the things that could go wrong on the performance phase of the product and their environmental impact, and consequently determine which are the major environmentally impactful characteristics that could go wrong and counter them in the design phase itself.

Out of the 5 simplified principles of Green Engineering given by [9], Principle 4, says that "Ideally net resources should be zero so that resources may be used at the rate equal to the rate of replenishment in the environment". [10] has given some techniques such as (i) reducing resources footprint and (ii) ensuring high reuse and low cost of reuse; and these techniques are directly implemented from the initial phase of engineering design that the products are engineered to have less resources footprint and designed for reusability.

B. Sustainability Engineering Toolbox

This topic was initially referred to the journal written by Tyler M. Harris and Amy E. Landis [11] and same as been interpreted here

The sustainability engineering toolbox contains set of quantitative methodologies to assist ensure indefinitely sustained social, economic, and environmental wellbeing [11]. Advancement to engineering systems can be made through sustainability assessments correlate well with cost savings and overall engineering system performance improvements [11]. The tools include Life Cycle Assessment (LCA), Social LCA (S-LCA), Techno-Economic Analysis (TEA), and Life Cycle Costing (LCC) [11].

LCC (Life Cycle Costing) is a tool that assists in determining the most cost-effective solution among multiple competing alternatives. The procedure to conducting an LCC method are similar to an LCA, and include construction, maintenance, and operations costs [12]. While often confused with LCA, LCC specifically tracks the costs, and while it can contain downstream costs such as maintenance and disposal, upstream cost value beyond the primary supply chain is typically not included [11]. All the costs are usually discounted and total to a present-day value, or net present value (NPV). The most common applications of LCC are in the construction industry and asset management; standards are set forth by ISO 15686-5:2017 [11].

The life cycle assessment (LCA) is a useful tool for quantifying and characterizing environmental consequences in order to improve the performance of a particular technical system cradle-to-grave performance [11]. LCA methodological standards have been developed and are widely used today [13]. The International Organization for Standardization (ISO) have published a series of pertinent reports on LCA standards: ISO 14040:2006 and ISO 14044:2006 [13]. ISO 14040 details four steps of and LCA [13].

1. Goal and Scope Definition,
2. Life Cycle Inventory (LCI) Collection and Analysis
3. Life Cycle Impact Assessment (LCIA), and
4. Interpretation of Results.

Each stages demand multiple iterations of previous steps, it often requires the updates and also advancements as more set of data, information and analysis are completed.

Important features of the goal and scope step are the system boundary and functional unit definition of the targeted engineering system [11]. The system boundary defines what lies within (and without) the scope of the study. LCIA is the part of the LCA, which will calculate and compares the environmental impacts utilizing established impact categories and characterization methods [1,14].

Process-LCA and economic input-output LCA are the two most common types of LCAs (EIO LCA), with a third approach, hybrid-LCA, which utilises a mixed approach of these methods [11]. Process LCAs are attributional in nature, and quantify and assess environmental impacts from each activity, product, or engineering process. (i.e., unit and system processes) included in the system boundary through careful study of system process details. For each process within a system, Process-LCAs use and tally significant datasets, including emissions, fluxes, and resource utilization [11]. Researchers at Carnegie Mellon University devised the EIO-LCA, which is now available for use at "eiolca.net". Using input-output information provided from the Bureau of Labour Statistics (Matthews and Small 2000) [11], EIO-LCA estimates environmental emissions resulting from economic activities (i.e., purchases) in the major sectors of the economy. Process-LCA and EIO-LCA elements and steps are combined in a hybrid LCA. Hybrid LCAs combine the two methodologies in a variety of ways. For example, in many cases, a process LCA model is created first, with missing process data augmented by EIO-LCA data or checked by EIO-LCA sector outcomes [11]. [11].

C. Utilization of Quality Function Deployment (QFD) as a method for Sustainability Function Deployment (SFD) [15]

This topic is initially referred to the journal written by Raid Al-Aomar [15] and same has been interpreted here.

Sustainability is frequently defined at the system level in terms of three bottom line aspects: economic, environmental, and social [16]. The interaction of quality and sustainability is emphasized by the emergence of Quality Function Deployment as a tool for designing sustainability into products and services. QFD aids in the translation of stakeholder needs into three sustainability aspects. QFD is seen as a targeted process for turning the voice of the customer into technical changes in product and service redesign [17]. QFD's major goal is to deliver goods that meet customer needs while reducing waste and conserving resources [18].

In a typical system, customer requirements never remain static and changes has to be made to the system to accommodate the customer requirement thus meeting the quality standard. QFD is typically used to update customers need by getting periodic feedback [19]. QFD is gained its popularity particularly after the success it shown in automotive industry [20]. Detailing of QFD is given in [17].

Various literature review has been done on QFD which can be found in [21] and [22]. These literature review states that QFD can be used in considering sustainability requirement in the design (i.e., Sustainable Function Deployment). For implementation of SFD, designers must identify the actions required to fulfil the requirements of sustainability. Few examples of QFD's sustainability application include Green-hospital design [23], Green manufacturing [24], Product design [25].

Previous research activity on sustainability helps us in understanding that sustainability is a System property not an individual property [26]. In order to integrate the concept of sustainability into all aspects of the System, QFD has been enhanced to serve as SFD and used for system-level sustainability [15]. SFD is methodologically structured to achieve the internal and external stakeholders' requirement when designing services, engineering systems. As a result, the main idea of QFD, "House of Quality (HoQ)," is renamed "House of Sustainability (HoS)," and is built utilizing six elements/matrices in a closed-loop design process that begins with sustainability objectives and concludes with sustainability metrics and targets [15]. This closed-loop structure allows identification of sustainable engineering design requirements that ensures customers need and stakeholders' requirements. The structure is of HoS for SFD is represented in Fig 4 with reference to [15].

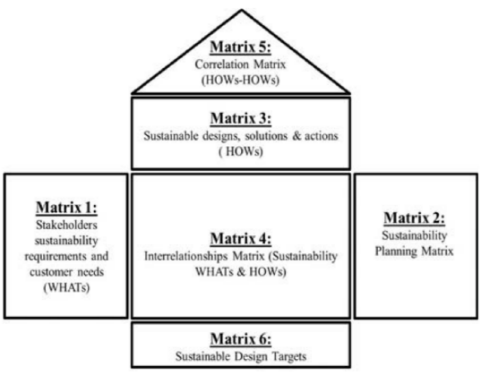

Fig 4: The structure of HoS for SFD [15]

The summary of the matrices is referred from [15] and interpreted here. In Matrix 1, Stakeholders' requirements are collected and is integrated with system user need. This is done through various channel of communication. The Matrix 2 represents the planning of sustainability with respect to Identified needs in Matrix 1. Matrix 3 represents the technical solutions or actions that include sustainability measures within the systems that is required to respond to customer needs. This phase improves the system design by including the sustainability notion. The Matrix 4 is used to verify the interrelationship requirements of stakeholders/customers and the developed sustainable design measures. This will clarify the "WHAT's" addressed using developed "HOW's" at a certain acceptable level [15]. After the completion of core mapping, Matrix 5 is used to verify the correlation with the developed sustainable design measures and actions [15]. While implementing sustainable design within the system, there might be a requirement which impedes or support another requirement. These negative corelations are viewed as an opportunity for innovative designs of sustainability to resolve such contradictions [15]. In Last phase, Matrix 6 is used to set specific target to attain sustainable requirement by assessing the propriety and weightage of discovered and formulated sustainable design actions.

III. IMPACT STUDY

The Impact of Sustainability is referred in this paper using previously conducted study by various authors in published journals. This paper refers and discusses two such example which can be used to understand the impact of sustainability of natural resources and its impact on engineering practices.

A. Case Study: FALCON 9 vs. HEAVY [11]

This case study was referred from [11] where complete study was analyzed and worked on by the authors of [11] and it is interpreted here to get overall understanding of the impact study.

Falcon 9, manufactured by SpaceX is considered to be successful commercial space vehicle venture. SpaceX is also in final stages of certifying the Falcon Heavy rocket vehicle design which is designed to considerable reduce the cost of orbital transportation by reusing two of its first-stage booster rockets [11]. A hybrid LCA method was utilized in study due to lack in process-LCA data on orbital transportation industry [11]. The result of the study [11] showed substantial reduction in all quantified impact categories in this study when compared using LCA and LCC on a per kg delivered to GEO basis (Fig 5 [11])

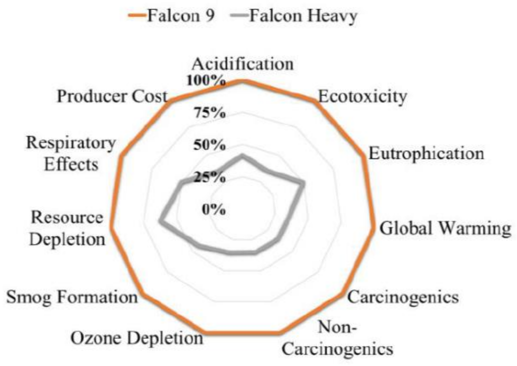

Fig 5: Falcon 9 & Heavy Life Cycle Impact Assessment Result Radar Plot Comparison. [11]

More detail on the study can be found in [11]. The result of these study illustrates both the economic and environmental benefits of applying principles of sustainability in engineering practices and how such benefits can be quantified [11].

B. Concept of Sustainability in Cement Production

This case study was reported from [27] where authors extracted complete work done by authors of [28-32] and it is interpreted here to get overall understanding of the impact study.

Limestone, clay, silica stone, coal, petroleum coke, heavy oil, and gypsum are some of the natural resources used in cement manufacture. To substitute limestone, ferric oxide mineral, clay, and silica stone, cement manufacturing techniques have concentrated on certain forms of waste, such as steel slag [29], non-ferrous slag [30], fly ash [31], or tires [32]. Wastes are mostly used as fuel and are immediately substituted for coal.

Gypsum has been directly replaced as an add-in element by waste (by-product gypsum). By utilizing waste produced by numerous businesses, Japan's cement industry contributed significantly to waste minimization in FY2008, i.e., around 29.5 million tons [33]. Simultaneously, natural resource usage fell from 1,559 million tons in FY2007 to 1,492 million tons in FY2008. In FY2008, waste utilization for cement manufacturing contributed to an 8,000 JPY/ton increase in resource productivity, from 353,000 to 361,000 JPY/ton. In total, 280,739 TJ of energy was consumed, with an extra 61,483 TJ of energy consumed if no wastes were used in cement manufacture.

IV.CONCLUSION

This paper discussed the basic understanding of sustainability and the survey of existing research topic helps the readers to understand how the concept of sustainability of natural resources is incorporated in the various levels of engineering process and quantifiable impact through the survey of performed case study in existing journals. The paper discusses on three topics under existing research topic which gives a clear picture of how sustainability is considered across the system design along different phases. The research study of newly proposed design includes designing process in regards to sustainability concept. The sustainability engineering toolbox contains set of quantitative methodologies to assist and ensure indefinitely sustained social, economic, and environmental wellbeing. Engineering systems advancement can be made through sustainability assessments along with relationship with cost savings and overall engineering system performance improvements. In the process of building a system, the QFD functions incorporate the customer's voice. Implementation of sustainability at systems level requires an enhanced QFD, SFD function. SFD is structured to achieve the internal and external stakeholders' requirement when designing engineering systems. The Impact case study of Falcon 9 vs. Heavy and Cement production helps in quantifying the impact of sustainability in designing process and its impact on designing process. Surveying these topics helps in understanding the overall impact of Sustainability of naturals resources on Engineering practices.

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Sustainable Utilization of Natural Resources in Production System and impact on Control Strategies

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***Abstract*—This paper discusses the sustainable utilization of natural resources in production systems and its impact on control strategies. To utilize and manage resources efficiently, every production company must have strict and defined policies adhering to standards and, most importantly, an energy management system in place. The energy management system allows the organization to apply a continuous PDCA cycle to implement the international energy management standard like ISO 50001. Energy-efficient manufacturing is no longer seen solely from an environmental standpoint. It is regarded as a crucial component of corporate strategy. Manufacturing enterprises are under constant stress as a result of high energy taxes, large energy bills, and ever-rising energy prices. Companies that employ energy management, on the other hand, have a huge opportunity to improve their financial situation and save money as a result. Standards have provided companies with a roadmap for moving toward green production. However, companies, particularly small and medium-sized businesses, are hampered by a lack of know-how and adequate tools and a lack of concepts and procedures for green production. The key to transforming a company from lean to sustainable green production is systematic and planned energy management. Several production systems control strategies such as MRP, Kanban, JIT and so on are discussed, along with the impact the resource allocation has on it are also looked upon in this paper.**

I. Introduction

In the past few years, sustainable and efficient utilization of natural resources have become increasingly important. This idea has been persuaded equally by the government and the businesses, backed by the society's desire for a sustainable environment and high energy prices. As a first step, it is important to make the renewable energy cheap, accessible and as a continuous source of energy. The German government has been facing several challenges in this aspect and has devised certain legal regulations. It has enacted Renewable Energy Act (REA) which made the renewable energy production to rise from 6.8% to 23% in the total electricity production in the country [1]. The energy cost is comparatively higher in Germany when compared to any other European countries. This high cost can be attributed to the EEG-Umlage, which is a renewable energy reallocation cost charged by the German government to finance the expansion of renewable energies. About 72% of Germany's energy requirement is met through energy imports, which exposes the country to additional increase in prices with supply risks [1]. The superior quality standards of products manufactured by German industries are attained through a very high degree of automation, as manual labour is very expensive [2]. This makes the energy cost a critical factor for the competitiveness of the production companies [3]. Therefore, more than the government, the industries itself must seriously start to consider improving energy efficiency in a sustainable way to remain competitive in the market [2]. Not only this, but production companies are major contributors to the environmental pollution, and this proves the importance of creating a sustainable and resource efficient production system and strategies. The target is to attain a transition from prevalently applied lean production to a more sustainable green production. This could be attained by having an efficient energy management system to enable this transition to produce sustainably. Control strategies such as push and pull techniques have been identified as an efficient tool to optimize the production system. Various techniques such as MRP, ERP, Kanban, JIT and TOC are different push and pull tools used in the control strategies, that is, different ways of allocating materials upon demand (forecasted or actual). The impact sustainable utilization has on these control techniques are also identified, and the environmental impact have demanded the companies to be inclusive and active in managing this impact. Shop floor and inventory control are also part of control strategies and by integrating key performance indicators with this, detailed knowledge on the impact can be achieved.

II. Sustainable Utilization of Natural Resources

Due to the need of lowering industrial production's environmental impacts, sustainability and sustainable manufacturing has become one of the subject for research in the era of Industry 4.0. In the manufacturing from low-volume to high-volume production, sustainable manufacturing challenges are extensively researched. It entails creating long-lasting products that take into account the entire life cycle, as well as applying sustainable manufacturing techniques and systems that reduce negative environmental consequences, reduce natural resource use, and conserve other resources. Innovation and creative thinking are fuelled by sustainability. Accelerated expansion in manufacturing and the design of new products is aided by innovation and the fostering of creative thinking. With suitable cost-time investment, societal well-being and economic progress are strongly reliant on the level and quality of optimized manufacturing systems [20].

To attain a sustainable way of utilizing natural resources in a production system, it is essential to have an energy management system in place. It allows the organization to have a standardized and efficient way to realize its sustainability goals.

A. Energy Management

Energy management is a well-defined way to deploy methods and measures for energy related task in a sustainable way. It allows the organization to implement a continuous improvement approach in terms of energy efficiency, with costs and uninterrupted supply as main factors [2]. An Energy Management System includes defining, installing, and controlling those parameters that are relevant to energies to achieve the goal of adequate, sustainable, and efficient supply of energy with ecological and economic aspects under control.

There are several guidelines and international standards for implementing energy standards at different levels. The depth of implementation is decided by the individual organizations based on their goals and requirements. Having an exemplary Energy Management System is the way for continuous energy efficiency optimization in a sustainable manner.

The ISO 50001 is the international energy management standard and this standard devises conditions for the complete harness of methods and measures of energy management as well as steps and procedures to achieve the strategic objectives [1]. The ISO 50001 is like other international standards such as the ISO 9001 for quality and ISO 14001 for environment management. These standards apply the Deming's PDCA Cycle and therefore, it allows the integration of new standard into already existing standards.

Approximately 50% of the total electricity cost in Germany are taxes and most of it contributes to EEG reallocation charges (around 80%). This generates a revenue of a whopping 7 billion euros for the German government every year [1]. The EEG Umlage is an incentive system introduced by the government for the production companies to control and optimize their energy consumption.If the companies could initiate a certified ISO 50001 energy management system, the companies can benefit from the reimbursement of most of the EEG charges.More than economic advantages, this enables the companies to reduce their greenhouse gas emissions. To attain an effective energy management system, the company must have a regulated resource management, which in turn will lead to sustainable utilization of natural resources. It pushes the companies to look for alternative sources of energy, materials, advanced technologies, and improved manufacturing techniques and this not only leads to reduction in energy costs but also increases the productivity and improves the quality of the output [4].

B. Implementation of Energy Management System

Even with these many benefits, a vast majority of production companies have not introduced an energy management system. The root cause for this is often the need of sufficient knowledge of the energy management system. In order to obtain ISO 50001 accreditation, a well-defined workflow must be implemented, and each step done to improve the performance of a system must be achieved in an appropriate manner. It takes a lot of time and money, and mostly the organizations lack the necessary assets to manage and operate an energy management system.

Furthermore, the potential energy savings that can be done by incorporating such a system is still not clear. Consequently, a clear communication and demonstration of resulting outcomes will be critical in reinforcing the adoption of energy management as a fundamental portion of an organization extending the Quality, Time, and Cost (QTC) triangle to Quality, Time, Cost and Sustainability (QTCS) tetrahedron making sustainability as a key decision-making parameter [1]. There are still several obstacles, such as employee resistance, misunderstanding about energy usage and the lack of knowledge about the optimization potential. Even today, many manufacturing facilities lack basic infrastructure for an energy monitoring system. This makes for the production companies difficult to find the energy and cost saving potential of their manufacturing sites. As a result, eliminating these low-level deterrents would be the primary step for execution of successful energy management system [5].

The energy management system can be implemented using either the existing ISO 50001 standard or a customized strategy. Whatever the approach (either standard or custom) is used, the core purpose is to maintain the relationship between the employees and the top management. The Plan-Do-Check-Act paradigm is the foundation of an energy management system. [15]

- **Plan:** Start with the energy audit. Benchmarking against similar models already on the market. Set objectives, targets and goals you want to achieve. Develop resources and actions in order to get the desired results according to the energy policy of the organization.

- **Do:** Implementation of action plan.
- **Check:** Observer the process and review the levels of target achieved. Examine the efficiency of an organization's energy management system in light of its policies.
- **Act:**Recognize the targets achieved. Take the required action to boost the energy efficiency and management system. Create new targets and objectives.

To ensure continual progress in PDCA, a specific sequence of actions must be followed for successful implementation of energy management system. The commitment of the top management considered to be the key step in this process and then the knowledge of accurate baseline of energy usage. Without the dedication of top management and a thorough understanding of recent energy usage inside a firm, the effectiveness of an energy management system is impossible.

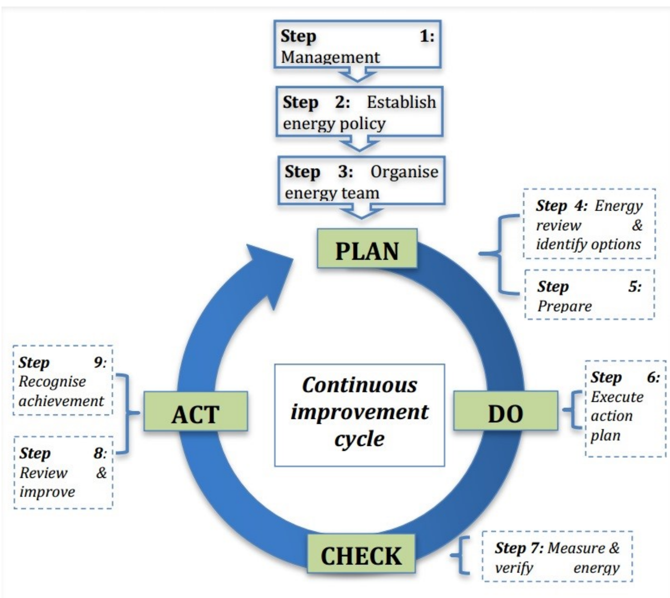

Fig. 1: Steps necessary for a successful model [16]

C. Benefits of Energy Management Systems

An energy management system helps businesses to track, analyse, and plan their energy consumption, giving them far more control over both operational and energy performance.Implementing an energy management system can result in significant energy savings through low-cost steps aimed at optimizing present operations, followed by higher-cost technological changes.The energy management systems prove to be the best practice system for ensuring long-term energy efficiency and continuously improving performance in industry. The majority of industrial enterprises that have implemented an energy management system have saved two to three times as much energy annually as those that have not implemented it.

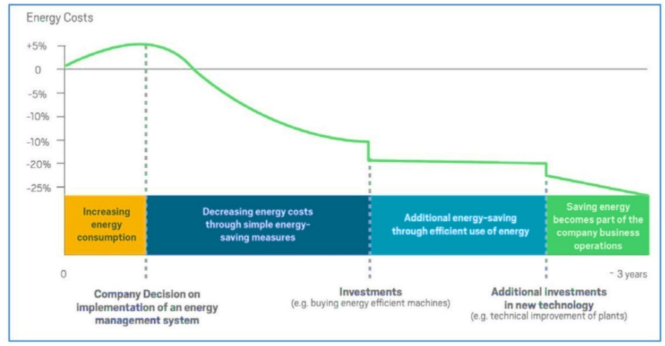

Fig. 2: Continuous cost reduction with an EMS [16]

III. Production System Control Strategies

Production process in this contemporary world uses innovative approaches of manufacturing and also look into the optimum usage of natural resources and planning and therefore modern production units are forced to optimize their operations to attain more sustainability. To meet the market demands and environmental stability, production processes embed all the relevant data into a single entity which is nothing but a fundamental principle followed from the era of Industrialization known as choosing from the best alternatives but as a modern approach, it is carried out in such a way that resources adequate for each stages of production are provided as a designated supply which is known as "control" production [6].There are various control techniques used in production processes to enhance efficiency and cooperation, as well as to decrease time and cost of production. Control strategies defined by push and pull instruments. Push reviews comprise Material Requirement Planning (MRP), Enterprise Resource Planning (ERP) and so on, while popular pull reviews include Just in Time (JIT), Kanban and Theory of Constraints (TOC) [6]. In a push system, central system place the orders for the work based on forecasted demand whereas, in a pull system, the current demand helps in scheduling the work [7]. Figure 3 illustrates the two concepts.

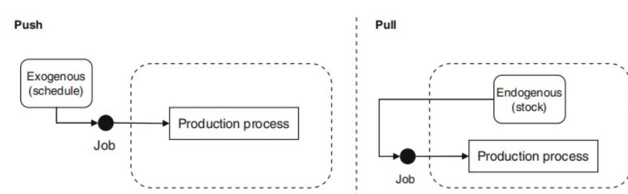

Fig. 3: Push and pull mechanics

A. Push Type PCS

Push strategies are implemented mainly by using MRP and ERP techniques. Material requirement planning method combines stock control with production planning, and allows solving the problems connected with labour coefficient of calculations and the time spent on data processing [6]. The final goals of MRP are to determine the time of supply of raw materials, utilization of infrastructures, production cost, faster reaction to changes in the environment and control over the realization of certain stages of production [7]. MRP basically calculate process start time and quantities for in-between products, which are mainly based on the forecasted demands of the final product. MRP requirement list includes forecasting demand and information gathering which includes warehouse inventory, availability of raw materials and bill of materials [6]. Even though there is sophistication in implementing these methodologies- forecasting, volume order and batches and date of delivery is pre-determined to a single entity which in turn reduced the required planning time and also helped in improving the efficiency.

ERP is another technique which supports management of organization for all of its important resources and for all the processes inside and outside the company. It implements most of the management strategies including marketing, cost, transportation and other approaches. This approach give an idea of the cost results of a company and enables precise forecasting of demand. ERP also emphasize on activities regarding order, production and distribution and also customer service, finance, supply chain, construction overview and technological changes and quality management [7]. ERP is known to improve the services provided to the customer to a much better value.

B. Pull Type PCS

Pull works on the actual working process of the system where it works on the basis of make-to-stock system, that is, ordered raw material is continuously replaced to fulfil customer requirement and production stock is provided only based on actual demands unlike forecasted one used for push strategy. Kanban is one of the popular pull-type implementation originated from the Toyota Production System where they used this in production system as a control technique [7]. KANBAN is a system of organizing the supply of parts or semifinished items, production resources when there is an actual demand for these elements [9].It also takes into account the time and volume required for producing the products. Specifically, in this method, production management is based on the flow of cards which contain information regarding materials and components necessary for production and are attached to carts which then deliver them for production.

Fig. 4: Example of a Kanban Card [10]

Just in time (JIT) as the name reveals is a pull strategy which takes into the account the stock of raw materials, intermediate resources, ready-made products in such a quantity and distribution time that it follows real time demand. JIT is based on avoiding wastage and also helps in improving flow of products and information [1]. Quality should be improved on a permanent basis which allows avoiding wasting time, resources and its usage, cost and losses, and eliminates inappropriate relations with suppliers and staff [11].

Theory of Constraints (TOC) is another pull strategy tool which takes into account the persistence of negative repercussions of restrictions and simultaneously removing or lowering them. CCMP (Critical Chain Project Management) and Drum Buffer Rope (DBR) are various approaches of TOC used for project management. CCPM takes contingency factor into account and helps in achieving all the basic goals of project management [13] whereas DBR focuses on scrutinizing the Buffet condition and in recognizing the factors which limits the production capacity [14].

Company	**Hampton Conservatories LTD**	**JOFCO Inc.**
Branch	Construction	Furniture
Location	Ireland	USA
TOC tools	CCMP	DBR
	EFFECTS	
Income	Increase	Increase by 30%
Storage	Fall by 70%	Fall by 60%
Net Profit	Increase of productivity by 100%	No data
Delivery time	Improvement by 60-90%	No data
Time of realization	Improvement by 50%	Improvement by 75%

TABLE I: Example of TOC Adaptation [12]

Various benefits of using TOC tools can be examined from the table.1 where it can be seen that the productivity was increased by 100% when Hampton Conservatories Ltd used CCMP tool of TOC. It is also observed that time for delivery and realization also increased by reducing the storage space. TOC also benefitted JOFCO Inc., that is, the income increased by 30% using this tool.

One of the drawbacks for push systems is that the work in progress for push systems is comparatively large and therefore, the pull strategies are highly recommended as a production control strategy even in cases where the push techniques are more commonly used as a control strategy [19] The impact of push and pull strategies on sustainability is huge, as the resources planning in these strategies plays a crucial role in finishing the production processes. The environmental imbalance has caused an impact in the way people approach the sustainability. The change in the perspective not only reflected the push and pull strategies, but also the whole production system as well. The strategy efficiency has caused the judgement power of the green production and the results of the green strategies have push and pull characteristics in them [18].The push communication strategies have the flow of information from the producers to the respective distribution channel and thereby the consumers also receives information regarding the same and demands green product. [18]

IV. Sustainability and impact on Production system control strategies

Manufacturing procedures that are optimized must have as little negative influence on the environment as possible. The multi-objective optimisation parameters for manufacturing systems must consider energy conservation (machine operation and idle energy consumption), natural resource conservation (natural material waste management), scrap reduction around assembly and remanufacturing, as well as repairability and disassembling. Sustainable manufacturing's primary goal is to bring a new holistic presence to the product cycle and optimize the lifecycle of manufacturing systems, goods, and services. System optimisation on three main objectives (minimizes energy consumption, material and product waste, optimises manufacturing processes and techniques related to manufacturing methods, production utilisation, manufacturing flexibility, lower production and labour costs, and high systems' efficiency); increased energy efficiency of operation and idle times; lower, cleaner, and renewable energy use with the optimisation of manufacturing methods, production utilisation, manufacturing flexibility, lower production and labour costs, and high systems' efficiency [20].

Sustainable use of natural resources has a significant impact on production system management strategies. The organizations are aiming to improve manufacturing efficiency while being ecologically conscious. Production control consists of determining if the resources needed to implement a production plan are allocated, and if not, taking corrective action to fix the defects. As the name implies, production control includes a variety of systems and technologies for managing production and inventory in factories. The most important topics in production control are: [16]

- Shop floor control: This production control system compares the actual progress and status of the plant's production orders with the production plan (MPS and MRP plan).
- Inventory control: Various approaches for managing an organization's inventory are included in inventory control. The economic order quantity formula is one of the most critical tools in inventory management.
- Enterprise resource planning: abbreviated ERP, is an extension of MRP II that includes all the functions of the organization, including those unrelated to manufacturing.

Today, society's awareness of corporate sustainability is so high that it is difficult to find a company that does not have "sustainability" anywhere in its mission, vision, or core value proposition. Furthermore, in the previous decade, every company has implemented lean improvement initiatives at certain points, displaying all the obvious features of lean in their factories. It seems that sustainability responsibilities are delegated to the factory operator, in line with a bottom-up approach, coupled with the advanced decision-making recognized by the factory.While this offers a lot of advantages, actual sustainability performance is restricted to carbon footprint(standard indicators) and you will miss the chance to design a truly robust sustainability plan. Nowadays, this is often the impact of sustainability on production control strategies. By explicitly integrating environmental and social Key Performance Indicators (KPIs) with financial indicators, sustainability Key Performance indicators can be included in control system performance parameters, allowing these companies to be proactive and inclusive of comprehensive sustainability goals. However, operators and production planners need new skills and training, which can be stressful and overwhelming. [17]

In contrast to shop floor control, inventory management and manufacturing resource planning have specific effects for the company's sustainable goals. Minimizing inventory has many environmental benefits. By reducing overproduction, you can reduce carbon emissions, reduce the amount of water used to make products, reduce the need for transportation, and reduce the cost of storing excess inventory. The environmental footprint of raw materials is gaining more and more attention, and reducing their impact is vital to achieving sustainability goals. By improving inventory management, you can minimize idle inventory, and this means speeding up your business's cash flow. [17]

V. Conclusion

It is now a well-established fact, sustainable utilization of natural resources in a production system plays a crucial role in the production companies. It assists in keeping efficient cost of energy and protecting the environment. As Germany is one of the costliest electricity providers, one could say that German companies have an extra burden to attain sustainability at an ideal level, or they might lose their market competitiveness. Standards such as ISO 50001 and ISO 14001 provide instructions for businesses to create in an environmentally friendly and energy-efficient manner. Still, a lack of know-how and a lack of sustainable green production methods and concepts make it difficult for businesses to transition from lean to green production. This study demonstrates that planned and systematic energy management is a good option for overcoming these issues. Energy management not only allows for tax savings, but also ensures that a company's overall energy use is optimized. The proposed energy management paradigm allows businesses to take advantage of the benefits listed above.

This paper demonstrates that sustainable utilization of natural resources is the first step toward a green manufacturing environment since quality, energy, and environmental norms and regulations may all be integrated into a single energy management and also focused on the impact it has on production system control strategies such as push and pull strategies. These control techniques were developed to optimize the production system as well as make the approaches in the production system more systematic. But while considering the resource management and sustainability, the control techniques get a little distorted as material flow is one of the important aspects in these push as well as pull strategies. A multi-stage production has different stages of resource allocation, so sustainable utilization of these resources may impact the way in which these resources have been allocated and distributed. Especially in a pull strategy, where resource planning is done quickly on demand, the distribution of resources may be hampered due to an over consideration of sustainability. Also, modern day production system is more lenient towards automation and flexible order management, so control techniques are all also on the verge of incorporating these changes. Overall, the scope of control techniques by considering resource allocation must be given a wider approach in the future.

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A Study on Variability in Production Systems: It's Impact on Efficiency and Effectivity of Production System

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***Abstract*— This study addresses one of the most important parameter of the production system, variability. Understanding variability and its effect in performance of production system is necessary. Hence the paper begins with the explanation, causes and classification of different types of variability. The paper further progresses to explain different factors which impact the variability and discussion in terms of measuring the variability with the aspect of efficiency and effectivity has also been presented. After analyzing the factors involved in controlling the variability, the proposed approach in terms of tools and methods which intends to boost the overall performance of production plant has also been covered.**

Keywords—Production System, Variability, Efficiency and Effectivity.

I. INTRODUCTION

In today's competitive global market, every business whether it be service oriented or product based is undergoing challenges to deliver reliable services and products with lower cost. The turbulence in market and innovation in technologies demands continuous modification in system architecture and operational parameters to secure profits and meet market demands [1]. Moreover, the challenge gets intense when the enterprises dealing with consumer-based products also need to address individual needs with products switching to shorter life cycles than ever before. The issue with individualized products tends to bother companies having make to order framework more than those with make to stock and build to order framework.

The production system is the basic pillar of Industry which helps structuring the whole manufacturing process. Proper study of dynamic behavior of production system and estimation of its performance relies on accurate investigation of factors including different elements, functions and interaction of functional structure within the system as well as with its environment. However, inevitable presence of random and unforeseen events in the system makes it difficult to accurately measure the performance. These random set of events give rise to variability in a system.

Variability comes into play when the performance of the plant/unit comes into play. It is categorized on the basis of value addition and the option if it can be eliminated or not. The Japanese approach of categorizing the waste into three types Muda, Muri and Mura helps in identifying the variability of system. Along with this approach of Toyota Production System, the variability can be measured and controlled with kaizen viewpoints.

Variability in the production system, production processes and even in the orders from the customers have a direct impact on the performance and efficiency of the plant [2]. Even while considering the example of Toyota Production System (TPS), variability is considered a fundamental part and given priority while designing production flow [3]. The primary factor that demarcates between a better performing plant with others is closely associated with variability in the system, stability in the schedules and reliability of the deliveries [4].

The available tools which can be used to reduce the variability and improve the performance of plant are significant enough to cater most of the general factors which impact the variability but the major factor which mostly impact the performance of plant is fluctuating demand of the customer.

II. LITERATURE REVIEW

A. *Production system*

The definition for the production system has seen variations with respect to content, emphasis and field it has been used. Adhering to the manufacturing domain, the production system is defined as utilization of resources like material, work and capital with an aim to create goods and/or services [5]. As per the black box principle [6], the production system can be considered as a transformation system with a black box, of which the contents are hidden and having several functions with a definite goal where operands (resources) are transformed from their original state to desired state (product) [7].
Based on production volume, continuity of flow and types of products produced, the production system is classified as:

- Engineer to Order (Job Shop Production)
- Make to Order (Batch Production with Mass Customization)
- Assemble to Order (Mix of Make to Stock and Make to Order)
- Make to Stock (Mass production)

In Engineer to Order production system, demands from the customers are specific and significant amount of further engineering analysis is required hence the industries are flexible. As we shift to other types of production systems, this level of product customization decreases. In Make to Order production system certain parts of the products are standardized and pre-built while some parts are built as per client's specifications, thus also called as batch production with mass customization. While Considering Assemble to Order production system the flexibility further decreases but the clients still have option to configure the products based on available parts during final assembly. In case of Make to stock production system level of customization is nil and the products are produced based on market forecast in huge volumes.

TABLE I. TYPES OF PRODUCTION SYSTEMS [8][9]

	Make to Order	Make to Stock	Assemble to Order	Engineer to Order
Focus	Product Specification and Customization	Sales forecast and Inventory Management	Configuration Management	Customization and Customer needs
Level of customization	Standard products with some level of final configuration	No Customization, Generic Products	End process customization	Complete customization
Feature	Mass customization	Economies of scale	Quicker delivery even with customization	Specifically tailored engineering and managerial approaches
Production volume	Low	High	Medium	Low
Pull/Push system	Pull system	Push system	Pull system	Pull system
Order promising	Depends on capacity of system	Depends on products in inventory	Depends on availability of major components/ sub-assemblies	Depends on engineering skills and production capacity

B. *Variability and Its Types*

Throughput time is one of the major key performance indices in a production facility. The productivity, quality and customer service of the organization depends to an extent to the reduction of throughput time [10]. Lower throughput time ensures consistency in quality, reliability in delivery and above all lower unit cost. However, lower throughput time itself is a consequence of reduced variability within the production system [11]. Variability includes a wide range of random and uncertain events in the production facility. The events could be introduced either in the process time or flow of the production [2]. The variability observed in process time can be due to breakdown of machines, time differences during setup, requirement of rework to maintain quality, operator availability, demands and specific requirements and many others. Similarly, variability observed in flow of production could be the result of working efficiency of operators and other factors that cause the inconsistent arrival time between each stage [12]. The effect of variability seen in one stage of production gets transferred to another stage and in some cases even an amplified effect is observed.

Plethora of literatures can be found discussing variability to be a crucial factor determining the performance of a plant. Variability always has its negative effect in performance of the production process and is also thus recommended to eliminate. However, as mentioned earlier, there are certain production processes where variability cannot be eliminated entirely. Moreover, there also exists certain processes where it is not recommended to remove the variability because of its value adding nature to products and production systems. For this reason, the Institute of Production System (IPS), TU Dortmund has developed a classification approach for variability [13]. The variability can be classified as:

- Non-value adding variability which must be eliminated
- Non-value adding variability which cannot be eliminated
- Value adding variability which must not be eliminated

TABLE II. TYPES OF VARIABILITY

	Types of Variability	
	Value adding variability	***Non-Value adding variability***
Approaches to deal	Variability Handling	Variability Reduction
Methods	System Design and System Flexibility Analysis Manufacturing System Integration and Automation	Just In Time Approach Value Stream Mapping and Variability Source Mapping

Compared to the Lean Production, the first class of variability in the system includes all sorts of Muras which are directly causing disruptions in production flow and have direct impact on production quality, throughput time, and ultimately the delivery reliability. This variability class is taken as the Mudas of production systems and it is recommended to apply the approaches of Lean Production to tackle them and completely eliminate them.

The second class of variability represents those non-value adding variability which can only be reduced in a system to some extent, but cannot be eliminated completely. Effects from non-deterministic factors which include influences of the production system's environment, influences of weather, effects from an unintentional accident, absence of an employee and many more fall under this category. It is recommended to minimize the occurrence of these variability in the system but a complete elimination is however not possible.

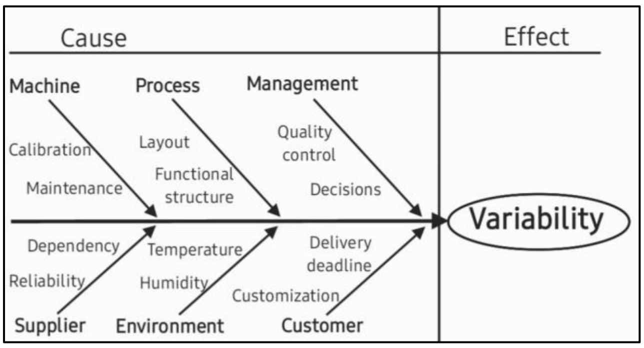

Fig. 1. Causes of Variability

The third class of variability represents the variability that increases the value of the products either as a whole or only to specific customers. These variabilities, though increases the complexities in the production process, are not recommended to eliminate from the system but rather its impact on the system should be mitigated. These variabilities may occur due to specific customization requirements and delivery date from the customers or by accepting rush orders.

C. *Effectivity and Efficiency*

Efficiency in production is to produce goods at lowest possible unit price and utilization of maximum available resources. Minimizing waste is a solution to achieve efficiency which can bring higher profit for the company. Simply, production efficiency aims at the maximum possible output utilizing the available assets. To give a further clarification about production efficiency, it can be described as the state when a system can no longer produce more goods without sacrificing the production of another product. Rather than the productivity level measurement, the number of resources required can also be considered as a factor of production efficiency. This can provide a balance between minimization of costs and maximization of resources, while maintaining a good quality of products.

On the other hand, effectiveness provides well-defined procedures which satisfies the demand of the partners and the company. It is normally described as doing things correctly. Moreover, when closely monitoring the functioning of a company it could be identified that in most of the stages in a production system, effectiveness outweigh efficiency. The effectiveness of a procedure is the proportion of how significant the output is to the desired goal. It is evident that to satisfy a client, everything should be done in a genuinely effective process. That is the correct outcomes at the perfect place and time and cost. Effectiveness mentions the extent to which planned results and planned activities are achieved. An ethical and well-functioning company follows its structure and well-defined work procedures to deliver a standard quality output product to its customers without sacrificing its reputation and demand in the market.

D. *Impact of variability in production system*

Variation is the major reason for the wastage of raw materials in a production system as they form interruption in the production system. Variation needs to be dealt with great care as they can dissipate through the production flow and affect productivity. The effect of variation depends on the design of the sequence [14]. Variation can occur in different forms and it is considered as an enemy in a production system as higher variability means added work in process (WIP) and less predictability in output [15]. When variation becomes significant it can affect either the production flow or the product. The productivity is also another victim of variation, as variation can affect the production flow, which gradually decreases productivity. The risk of errors and rework in production can grow exponentially as a result of variation and it can directly impact the quality of the product [16][17]. Mentioning about presence of variability in the quality of final product itself, as customers always expect both uniformity and low cost, the variability can downfalls both these objectives. The production system with variability always inculcates high cost and non-uniformity [18]. When selling a highly variable product there can be three broad outcomes. The first one is unsatisfied customers with the intended purpose of the product which they bought it for which makes the product value less. Considering an example of an engine oil with unsuitable properties that causes engine failure. Another outcome is the impact on performance of the product. It can be undoubtedly stated that a product with variability lacks in its performance and the user must invest additional cost to compensate the poor properties. As mentioned in the case of engine oil with insufficient standard, the engine may face failure as the standard required for smooth operation is not maintained in the oil which has been used. The impact directly effects on the customer who owns the vehicle. And the final outcome would be, the value of the product and its fame in the market is deteriorated. Even though the product may be acceptable in future but people buy with suspicion considering the worst past experiences.

Linking the effect of variability with throughput time, mathematical relation given by Kingman in 1960 explains the elongation in throughput time with respect to increasing variabilities in the system [19]. Variation combined with high-capacity utilization has a severe impact on throughput time. This draws the attention to focus on minimizing the variability. Bicheno connects the Kingman formula with the concept of Muda, Muri and Mura used in the Toyota Production System. Emphasis to take notes for variability in processes and arrivals within a system and to make efforts to figure out the bottlenecks in areas with high levels of variability have been made in his work [20].

Variability in a production system is always taken as an aspect to be reduced and eliminated [21]. But in case of enterprises with a make to order framework, where sources of variability are from customers including delivery dates and individualized parts that adds value to the products for particular customers, complete removal of these sorts of variability from the system is not suggested. Rather approaches should be adopted to minimize the impact of these variability on the system to achieve a profitable cost benefit ratio [22].

E. *Approached to Deal with Variability*

The variabilities seen in a production system can be of both value adding and non-value adding nature and thus separate methods should be applied to deal with each category. Following are the suggested ways;

1) Concept of variability reduction

- Application of Just in Time approach

As defined by William J. Stevenson, Just in Time approach can be explained as “a repetitive production system in which processing and movement of material and goods occurs just as they are needed, usually in small batches” [23]. Just in time involves “having the right items of the right quality and quantity in the right place and at the right time” [24]. The major focus of JIT is towards the value adding activities and elimination of waste [24][25]. Inventories are responsible to absorb the variabilities (non-value adding) in the production systems [26][27][28]. The presence of surplus inventories can and will be used to cover the variations and problems in the production systems. But with the application of just-in-time philosophy which strives for a level of zero inventories, the hidden variability in the system comes into full view and it is much easier to deal with these exposed problem sectors [29]. In the scenario, where non-value adding variabilities are considered, using the JIT approach in a production system, the variabilities can be reduced and even eliminated completely with its proper implementation.

- Value Stream Mapping and Variability Source Mapping

Value Stream Mapping (VSM) is a tool used to capture value adding and non-value adding activities and applying it to what Ohno said "to reduce the timeline from the moment a customer gives an order to the point of cash collection by reducing the non-value-added wastes" [30][31]. VSM is used to map the complete production process that includes the material, information and signal flow in the system. However, the current practice of lean manufacturing is found to be more focused towards time minimization and waste elimination which is unable to capture variability and its source [30]. Thus, a new tool Variability Source Mapping (VSM-II) has been introduced to complement the existing VSM which aims to include the variability in the production system. The tool provides overall variability as well as stage by stage variability for a production system with a metric named as Variability Index (VI). The output of the tool is Variability Reduction Plan (VRP). The stepwise implementation procedure of VSMII in a production system initiates with selection of the production family. Then the material and information flow in different processes are mapped to measure the existing variability in terms of time and flow. Once the process of mapping and measuring is completed, the level of variability is identified and locations and stages with high value of variability index are figured out. Based on the existing Variability Index a new target is set and a Variability Reduction Plan is formed and implemented.

2) Concept of variability handling

- System design and System flexibility analysis

The major change forces to be tackled in production business includes changing customer demand, diversified market and shorter product life cycles [32]. Life cycle of products is very short in comparison to production systems. So there lies a grave need to plan beforehand about the requirement of production capabilities in future. Issues concerning flexibility and compatibility have to be addressed because of the differences that may occur between the stimuli acting on the firm and the proactive strategies of the firm [33]. The ideology behind this approach is that the system design should be proactive enough to include the possible variations that a product might face due to market diversity or ever-changing customer demand and thus set up a flexible production system. The state of art for system design and system flexibility analysis have been considered to propose three major steps to handle the variability that may occur in the production system [33]. Major emphasis has been given to system flexibility and the developed model for this production system has been named Focused Flexibility Manufacturing Systems. (FFMSs) [34]. The proposed steps to reach the aim of flexibility are:

a) Identification of Basic Flexibility Forms

b) Integration of new concepts in the Flexibility theory

c) Translation of Flexibility Forms into System Specification to design the Production System

- Manufacturing System Integration and Automation

In order to handle certain portions of variabilities existing in production processes, application of two major manufacturing strategies: integration and automation is recommended [30]. Automation in the manufacturing process is achieved through application of Advanced Manufacturing Technologies which includes use of CAD/CAM, FMS and CIM at different stages of production. With CIM applied in processes of manufacturing, automated flow of information between correlated processes is facilitated. Further, application of CNC machines for fabrication, ASRS for material handling and other NC robots supports in reduction of throughput time. Likewise, application of FMS enables the production of a variety of products from a family to respond to new design demands from clients [36]. Thus, through automation, variability handling is dealt through increasing the level of flexibility and instant information flow and quick processing time. However, the findings from case studies and other literatures suggest that numerous companies that have made investments and adopted advanced manufacturing technologies (AMT) have been unable to gain expected benefits [37][38][39]. Some of the published works have tried to address this issue and proposed implication of Manufacturing System Integration prior the adoption of AMT [40][41][42]. Further, in [43] it has been recommended to attain manufacturing system integration through organizational system design rather than technological system design. The system integration should include not only the manufacturing portion but also the activities like material handling, purchasing, scheduling, design engineering and many others. Integration along the value chain should be considered as the initial response step towards uncertainties in the system and only then flexibility should be introduced. Thus, for an optimized system that is able to handle the variability induced in the system, a highly integrated yet flexible system is recommended which is possible through Manufacturing System integration followed by Automation. Yet, it is suggested, methods of variability handling should only be implied once the methods of variability reduction have been implied and variability has been reduced as much as possible [43].

III. CONCLUSION

For different types of production systems ranging from customer order driven or market forecast dependent, variability plays an important role in all aspects. Variability can vary on the approach if it can be controlled or eliminated. It is also dependent on the part if it can add value to the system or not. However, in few cases, it's recommended not to eliminate the variability as it's adding value to the product or process itself. It's clear from the research, that variability is meant to be dealt with great care as it impacts the whole production system and sometimes it's dependent upon uncertain and random events. And the quality of the product may also be impacted.

Variability can be dealt with few approaches of lean production and most of the Mudas & Muras can be eliminated from the system. One of the approach is Just in time (JIT), usually high inventories help to absorb the variability but with JIT approach hidden problems can be explored easily and worked upon. Apart from JIT, there is a VSM approach which works on minimizing the time by working on information and signals along with materials. And to measure dynamic nature of variability, variability source mapping is added and it has a variability index which is used to make the variability reduction plan. Nowadays, the systems are designed flexibly to manage the variability with the model of focused flexibility manufacturing system.

Thus, while dealing with the variabilities in the production system, approaches like JIT works in the area for variability reduction by creating a manageable environment for tackling them whereas application of advanced manufacturing technologies and system integration works for handling the impacts that variability can induce through application of flexibility in the system.

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Survey on Asset Adminstration Shell in Productions Systems Engineering

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***Abstract*—This paper is a survey that describes Asset Administration Shell component of Industry 4.0 and its functions. It further summarizes how it will change production systems engineering by referencing example of its role in PLM, Manufacturing systems, mini factories, and Plug & Play smart manufacturing. It also gives a brief introduction and explanation on Industry 4.0 based off RAMI model.**

Keywords—AAS, RAMI, Industry 4.0, Mini factories, Plug and play.

I. Introduction

"Screws communicating with assembly robots, self-driving forklifts stocking high shelves with goods, intelligent machines coordinating independently-running production processes – people, machines, and products are directly connected with each other: the fourth industrial revolution has begun" [1]. The advent of electronic devices and IT in the 1970s brought forth integration of computing devices into production to increase profitability and efficiency. The German origin Industry 4.0 started with the industries' move towards automation integration and data exchange between various assets and across several hierarchical levels within the automation pyramid. Thus far there has been several attempts at creating a unified theory of architecture for Industry 4.0. These architectures involve the use of manufacturing technology and process such as Internet of things (IoT), Cyber physical systems CPS), big data, cloud computing, cognitive computing, Artificial Intelligence (AI), marking the start of Imagination Age. Global trends like mass customization, flexibility on demand, adaptability and decentralization have played a significant role in the arrival of the 4th Industrial Revolution. Industry 4.0 offers its own complexities. The move towards digitalization and networking by several companies for their process has created several interfaces between actors. This creates the need for a set of uniform norms and standards across several sectors of the manufacturing industry.

The need for a standardised approach to Industry 4.0 gave way to Reference Architecture Model for Industry 4.0 (RAMI) which is a three-dimensional guide towards structuring of an Industry 4.0 based system. It is a service-oriented architecture which combines all non-IT and IT components with the hierarchy and the product lifecycle. Asset administration shell is a concept, based on the theme 'Digital Twin', derived from the RAMI model.

II. ISA 95 vs RAMI 4.0

ISA 95 and RAMI 4.0 were developed as framework references as per the need of the industry at the time of definition.

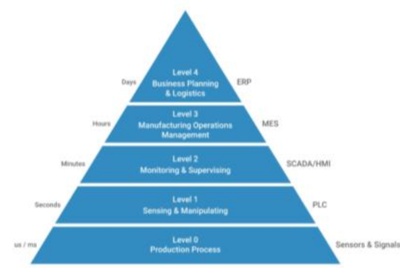

Fig 1: ISA 95 Reference model for Industry 3.0 [2]

ISA 95 was developed in line with Industry 3.0 as shown in Fig 1. It is an international communication standard to facilitate communication between the different hierarchies in the enterprise system. At the lowest layer are the physical process and entities including control of machine physics, processes, and sensors. The second layer consists of the control of basic production processes consisting of embedded intelligence. The middle represents control of complex production processes within the production system and order control applications. Fourth layer shows the control of production units such as material, resource, and staff. The highest layer of the automation pyramid relates to the coordination of different companies in the production workflow. This framework goes on to describe the different interactions and helped standardized the communication between each of these layers.

RAMI 4.0 was proposed by the Platform 4.0 initiative to give companies a framework for developing future products and business models. It outlines the requirements of an Industry 4.0 component system in a structured way, exploring lifecycle, hierarchy and functional layers as shown in Fig 2. It enables stakeholders to adopt a common perspective and understanding of Industry 4.0 resources and assets.

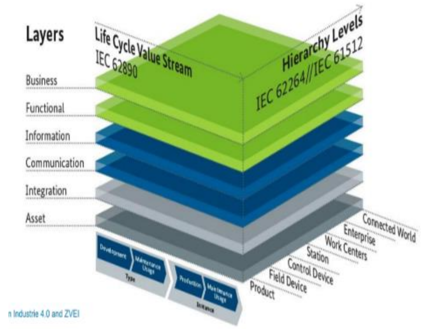

Fig 2. RAMI 4.0 portrayed by Platform Industry 4.0 and ZVEI [3]

RAMI 4.0 consists of 3 axes: Hierarchy level axis, layer or architecture axis and life cycle axis. Fig 3 shows the hierarchical layer which in contrast to framework of ISA 95. ISA 95 focuses on just the interaction and communication of the different layers. RAMI model shows that all layers are interconnected across hierarchy layers. Communication occurs among all actors and allows for distributed function throughout the network. The hierarchy axis describes the necessary advancements that need to be implemented.

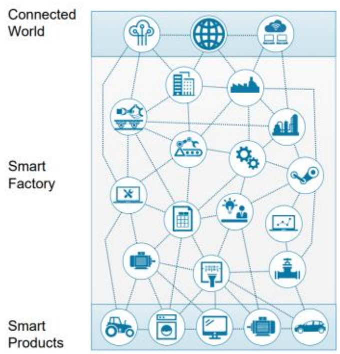

Fig 3 Hierarchy axis : The factory [4]

The second axis is the life cycle and value stream axis which depicts the lifecycle of products, machines, factories and other assets and their associated value stream according to the IEC62890 standard. The purpose of this axis is to record all data of an asset, form its first idea and initial design, all the way until the asset is scrapped [5]. This framework guides the idea that each entity in the system is tracked from creation till end of its lifecycle.

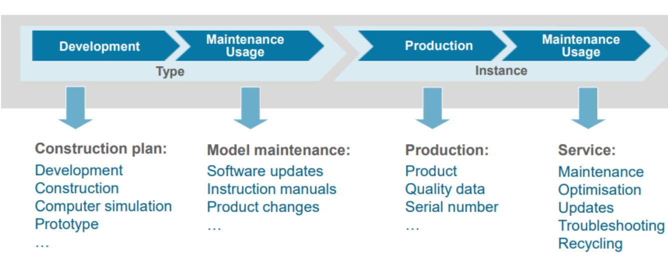

Fig 4 Life cycle axis [4]

Fig 4 shows the different operability layers in the RAMI model. It represents different functions and data relevant to the other 2 axis. It describes the necessary advancements need. The core structure of this axis is based on IEC62264(Enterprise control system integration) and IEC61512(Batch control) standard within a manufacturing environment [5]. The physical things refer to all real-world assets and actors.

Fig 5 Architecture axis [4]

From the Fig 5 it is seen that one of the key aspects to establish Industry 4.0 is the convergence of the real-world physical things and the digital network. This is termed as 'Digital Twin', precisely defined, and is currently interpreted in different ways in industry. It is primarily used to characterize the digital replica of an asset with all the information relevant for a specific engineering activity. Digital twin barely exists as a theoretical concept, whereas an asset administration shell (AAS), is a practical and standardized approach for implementing Digital Twin [6]. AAS is the interface connecting the physical thing to the Industry 4.0 network. It is the standardized communication interface that stores all data on the assets able to integrate everything from the physical world.

III. Asset Adminstration Shell (AAS)

Asset Administration Shell (AAS) is the digital representation of an asset.

Need for AAS [7]

- Implementation of Digital Twin for Industry 4.0.
- Cross-Company Interoperability
- Common platform for intelligent and non-intelligent products.
- To monitor the complete lifecycle of any element in the system.
- Integration of Value Chains
- Digital Model for autonomous systems and Artificial Intelligence.

AAS is significant constituent of Industry 4.0, making a point of interaction between the physical and Digital Twin. It contains functional and structural data of asset, and it manages communication with external components Any production component in the I4.0 environment has to have an administrative shell [8]. With AAS virtualization optimization and monitoring of algorithms and economy of production is possible. Due to the flexibility and robustness of the digital twin through AAS, a decentralized production system is achievable. AAS consists of several sub models in which all the information and functionalities of a given asset – including its features, characteristics, properties, statuses, parameters, measurement data and capabilities – can be described [13]. This information is tracked in AAS from the initiation of the object to the end of its lifecycle. It allows for the use of different communication channels, applications and serves as the link between objects and the connected, digital and distributed world [13]. The following are some characteristics of AAS.

- AAS describes the information content and serialization formats of an Asset Administration Shell. [14]

- It specifies a technology-neutral UML (Unified Modelling Language) model, an XML (Extensive Markup Language) and JSON (JavaScript Object Notation) schema and mappings for OPC UA (Open Platform Communications United Architecture), AutomationML and the Resource Description Framework (RDF). [14]
- It includes a definition of the AASX exchange format, which is used for the secure transmission of Asset Administration Shells [14]
- It takes account of security aspects and defines access rights for information stored in the Asset Administration Shell based on the Attributes Based Access Control (ABAC) concept. [14]

Figure [2], depicts the structure and connection between a physical asset and its corresponding administration shell (AS). The AAS consists of a body and a header. The header contains identifying details regarding the AAS and the represented asset, and the body comprises a certain number of sub models to facilitate the asset-specific characterization of the AAS [15].

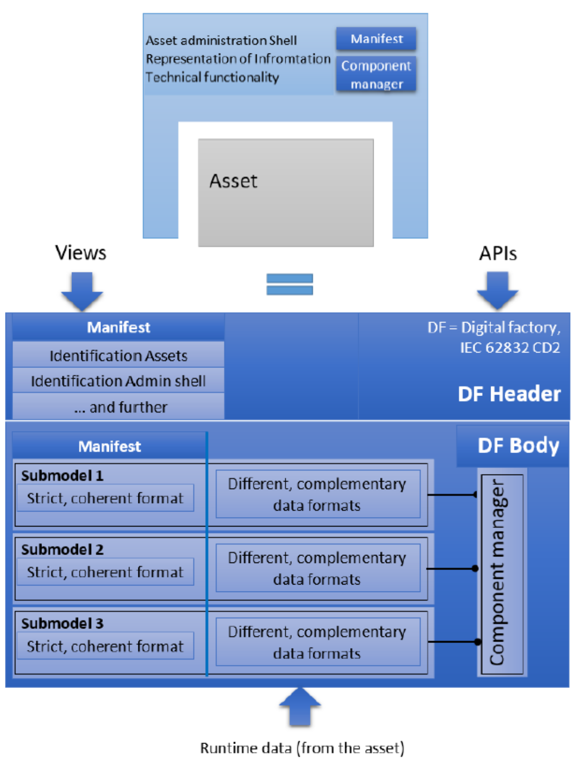

Fig 6 Asset Administration Shell [16]

Each sub model represents a different characteristic of the asset. The sub model may contain attributable, functional, or structural information about the asset. The properties of the submodel are stated according to IEC 61360 which forms the guide for various format and functional representation. Fig 7 is an example of various sub model framework with standard guideline for several type of sub models

Administration Shell IEC TR 62794 & IEC 62832 Digital factory	
Submodels	**Standards**
Identification	ISO 29005 or URI unique ID
Communication	IEC 61784 Fieldbus profiles
Engineering	IEC 61360/ISO13584 Standard data elem.; IEC 61987 Data structures and elements; Ecl@ss database with product classes
Configuration	IEC 61804 EDDL; IEC 62453 FDT
Safety (SIL)	EN ISO 13849; EN/IEC 61508 Functional safety discrete; EN/IEC 61511 Functional safety process; EN/IEC 62061 Safety of machinery
Security	IEC 62443 Network and system security
Lifecycle status	IEC 62890 Lifecycle
Energy Efficiency	ISO/IEC 20140-5
Condition monitoring	VDMA 24582 Condition monitoring
Examples of AAS usage	Drilling, Milling, Deep drawing, Clamping, Welding, Painting, Mounting, Inspecting, Printing, Validating ...

Fig 7 Possible Asset Administration Shell Sub models [17]

IV. AAS in Production Systems Engineering

The following section focuses on how AAS has changed production system engineering. AAS' role in the whole if System's Engineering is vast hence this survey is focused only on its application in Product Lifecycle management (PLM) [18], in mini factories [19], plug and produce [6]. The scope of this paper only introduces these topics and the role AAS has played. To understand the detailed implementation of AAS in these individual fields, the original paper needs to be referred.

A. AAS in PLM

Product lifecycle management overshadows the entire process from the conception of a product till the end. The holistic organization of the product lifecycle of these products and systems based on methodical and organizational measures using IT systems is called product lifecycle management (PLM) [18]. PLM, over the years, it has tried to integrate itself into every field and practice with the help of specific interfaces. But these interfaces are highly vendor dependent. Though PLM has successfully established itself in several fields it does not cover all functional and attributional data of the product. The variety of IT and IT integrated systems makes it difficult to maintain continuous chain of management in PLM. There have been some efforts to reduce this difficulty by the introduction of STEP and JT formats which allow smooth interconnection, it still poses a challenge in the field. According to [7] the following challenges are included

- Due to individual item naming in the systems, different interpretations of an artefact occur within companies.
- Different data formats are used for the same processes.
- Data should be accessible in such a way that it can also be used in areas for which it was not intended when it was

created. This also includes independence from the location as well as from the company.
- The completeness of data cannot be guaranteed because it is often stored in different data repositories or even exists as documents in digital or paper form.
- Data access is hindered by data security requirements.
- Effort is needed to make the data of one PLM system accessible to other systems.

Additionally, PLM is not equipped to handle creation of digitized products or digitized systems otherwise known as digital twin. To counter this issue Application Lifecycle Management (ALM) was developed, however these tools can only be used as a parallel to PLM. The other problem raised is that these are again vendor specific. Thus, when working with several vendors as a part of a complex system the task of creating custom interfaces becomes humungous. The emergence of Digital Twin concept promised to a viable solution for this current issue. However Digital Twin only existed as a concept with no viable solution. Thus [18] suggests the use of AAS approach to this problem. Both PLM and Systems engineering deal with products of interdisciplinary nature. However, System's Engineering is independent of any IT tools and its methods are flexible to accommodate several fields. A central technology for implementing Digital Twins can be seen in AAS. The AAS specification does not define how to implement an AAS. However, to provide standardized implementations of the AAS from different vendors, several initiatives are currently active, including the AASX Package Explorer [18].

The major research of [18] were focused on a few application scenarios namely,

- OCP—Order-Controlled Production.
- AF—Adaptable Factory.
- SAL—Self-organizing Adaptive Logistics.
- VBS—Value-based Service.
- TAP—Transparency and Adaptability of Delivered Products.
- OSP—Operator Support in Production.
- SP2—Smart Product development for Smart Production.
- IPD—Innovative Product Development. [18]

There are 2 major requirements that [18] addresses: the PLM-AAS concept in question must be based on a standard independent of the vendor and all data created for and by the asset should be able to access outside the system in question. In addition to these 2 fundamental requirements the research also focused to fulfill some higher functional requirements specifically in relation with the PLM tool (Teamcenter) and1. ALM tool (Polarion).

Fig 8 depicts the design concept and its implementation as per [18]. Firstly, the research team created a AASX package explorer. The data from PLM was exported as an PLM XML file and ALM data was exported as ReqIF (Requirement Interchange Format). Then using a special importer these files were taken into AASX package explorer. The ALM data was imported directly into a sub model ALM part of the AASX. A separate AAS relationship class was defined within the AASX explorer to formulate the relationship between the PLM data and ALM data.

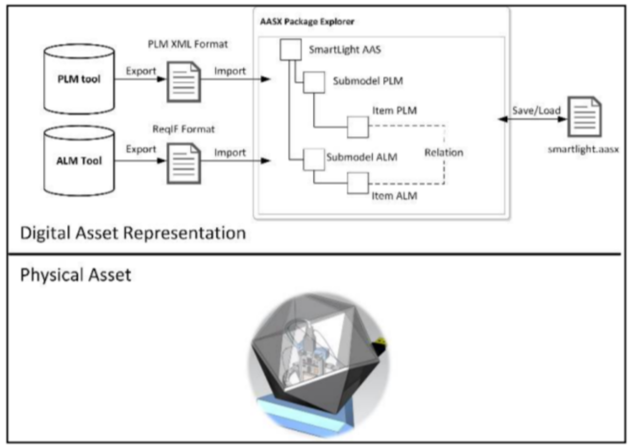

Fig 8. The design concept for PLM/ALM mapping to AAS [18]

This AAS based PLM/ALM model was evaluated and verified with the previously mention application scenarios: OCP, AF, SAL, VBS, TAP, OSP, SP2, IPD. In all these application scenarios the newly created AAS based PLM/ALM performed better if not equally good showing very optimistic outcomes.

B. AAS in Mini Factories

The research paper as per [19] argus that the approach towards implementation of Industry 4.0, even as this concept permeates into the existing production system, is through modularity. [19] presents a methodology to create AAS in Mini Factories thereby enabling modularity. It is believed that the future of manufacturing sector will not be comprised of large factories but rather several modular, controllable mini factories. The idea of mini factories allows for the establishment of 2 desirable concepts: Mass Production and Mass Customization. Mass Customization allows for tailored products to the customers needs while also not losing the benefits of mass production. Though there have been several works published on the modelling of AAS there is but little research on how to establish the connection between the real-world asset and its digital twin and additionally most work doesn't deeply explain scalability and agility that is becoming an increasing requirement. This paper [19] systematically focuses on integration of AAS in existing assets in manufacturing shop floor.

The research of [19] recognises the digital twin is strongly linked to the implementation of Industry 4.0. It shows a simple approach to the implementation of AAS through 3 different stages. It aims to bear a digital twin that is constructed and elaborated to have one on one functional relation to the physical asset it represents.

Stage 1: Definition of AAS variable: Relevant variable and sub-models pertaining to the specified physical assets are discussed with the domain experts. As per RAMI 4.0 AAS only contains the property definition and property characterization. This is only sufficient to outline the knowledge model of AAS. [19] believes that it is important to also include the variable usage information, which include data in use characteristics. This is essential for connecting the asset with its Digital Twin. In [19]'s approach it introduces Property Usage [19].

2. **Stage 2 AAS Modelling**: This stage streamlines the information from stage 1 and disconnect the data and usability model. AAS structure has been automatically developed with the use of templates. These templates produce a JSON or RDF or XML file. The process is completed using python that parses the information from stage 1 creates a serialized AAS. Version control software is used for traceability.
3. **AAS Connectivity with the real asset:** This stage involves the creation of database and communication protocol along with integration with IoT to connect with the asset. Stage 1 already covers the database creation and thus, if required, an OPC UA tree for both the server and client can be created. Most OPC UA SDKs have an automatic feature to allows the creation and consumption of XML-type files [19].

   The Fig 9 shows the flow of the 3 stages.

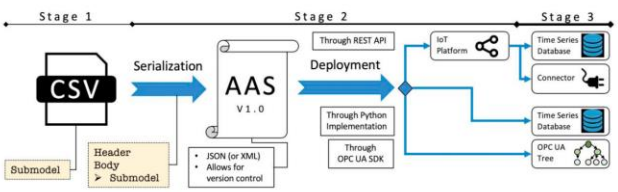

Fig 9. Flowchart of the three-stage methodology to create and deploy the AAS [19]

The research also conducted a case study on ARTC-Singapore applying this use of AAS in a gearbox factory. The detailed modelling of the application of this concept to the gearbox factory can be seen in [19]. It proves the successful implementation of AAS in mini factory setup.

C. AAS in PnP

The goal of the referenced paper [6] is to design a method for implementing AAS and to develop an AAS enabled digital solution in the manufacturing sector. It aims at AAS based digital solutions in Industrial cyber physical systems. Fig 10 shows the field assets, edge AAS deployment, and cloud AAS management as part of a 3-layer architecture. OPC UA forms the fundamental network this 3-layer architecture. Field assets relates to the physical asset while the other 2 layers are part of the digital twin.

1. Field Layer- Includes all assets. Assets include both hardware and software entities. Each asset is assigned an individual OPC UA server which contains detailed functional and parametric information of the asset. Thus, each asset is digitized.
2. Edge AAS Deployment- This serves as the platform to run each asset AAS. It is in this layer that the individual AASs interact and run with the entire network. It is specifically accomplished through AASX based OPC UA server. It also contains Edge interface for its interaction with the previous layer.
3. Cloud AAS Management- Cloud layer is used to manage the several AASs

The research also covers the application of this system in the context of plug and produce system. PnP systems are more flexible and help in the creation of a so-called Adaptable Factory.

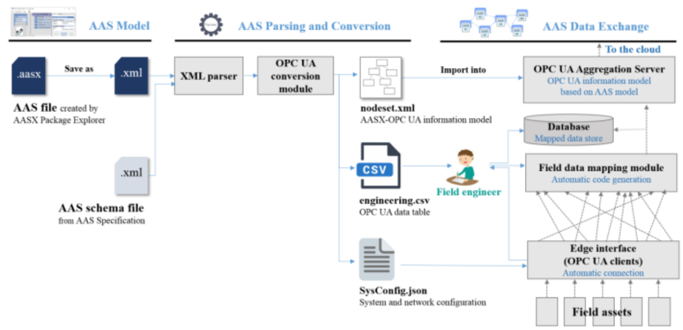

Fig 10. AAS Deployment [6]

With this feature it allows new asset allocation, asset re allocation and asset disconnection with minimal to zero configurational changes. The research evaluates the feasibility of such a system with AAS. It involves the following steps:

a) *physical setup- 3 different robots and their controllers*
b) *pre-integration- the robot system and turn table were connected to the field integration bus*
c) *digital representation- through AASX-OPC UA aggregation server and edge interface*
d) *AAS communication- through AASX-OPC UA aggregation server and edge interface*
e) *system assessment- using e AAS web UI by analyzing the AAS data.*

As per the research discussions The PnP function is implemented on an application level, currently, it is only applicable to the turntable and robots. In other words, robots and turntable operate based on the PnP strategy defined on the web UI [6].

V. Conclusion

To say AAS will affect how production systems engineering will be approached in the future would be an understatement. From the briefly mentioned few cases and applications scenarios one can identify how AAS will redefine the current production system. AAS will play a key role in shaping the future of Industry 4.0 and leading further into Industry 5.0. But to achieve its full vision in the context of Industry 4.0, it requires several interdepartmental co-operation in companies and personnel trained to manage such interdisciplinary complex problems, in this move towards complete digitalization. One should note that it also arises concerns with cyber security as we move towards a CPS idea. However, though the idea of AAS has been introduced there is still a lot more research required in this area to full establish the concept of AAS. The survey results show the variation of AAS application in several asset and its uniqueness to each type. There is also a requirement to establish a standardized model and data format for application through all sectors, though Platform 4.0 has given an outline. The work of digitization of the assets can be reduced if assets are designed with the idea of AAS right from conceptualization. Thus moving forward, the systems engineering approach has to re-envisioned and amended with the fundamentals of Industry 4.0 such as AAS integrated into it.

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AutomationML component and its impact on production system engineering

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***Abstract*— This paper describes about the AutomationML component and in order to explain comprehensively about AutomationML Component brief description of AutomationML has been given. Information regarding use cases for the exchange of Automation Components and sub-modelling of AutomationML components is comprised in this paper. Description of a logic representation and simulation of automation components has been demonstrated. The concept of AutomationML components affecting production systems using tool chains and use cases has been exhibited.**

Keywords— AutomationML, AutomationML component, stake holder, logic representation, Virtual Commissioning

I. INTRODUCTION

AutomationML is an XML based data format pursuing the data exchange between heterogeneous engineering tools [1]. The goal of AutomationML is to interconnect engineering tools in their different disciplines [7]. The main target of application AutomationML is developed for is the field of production systems engineering and commissioning [8]. AutomationML (AML) offers a way of modelling automation components such that the models are stored and exchanged through different parties involved in the engineering process of an automation plant [2]. AutomationML components describe automation components or systems. The definition of an automation component can be either a type or a model. Additionally, automation components do not contain sub-components. AutomationML Components are stored as SystemUnitClasses or InternalElements. When AutomationML Components define a type model, SystemUnitClasses are used. When describing an instance model, an InternalElement should be used. AutomationML Component models represent data models for a specific domain or use case. Generally, in many cases within engineering and subsequent use of an AutomationML Component, using single domain models together provides the best results.

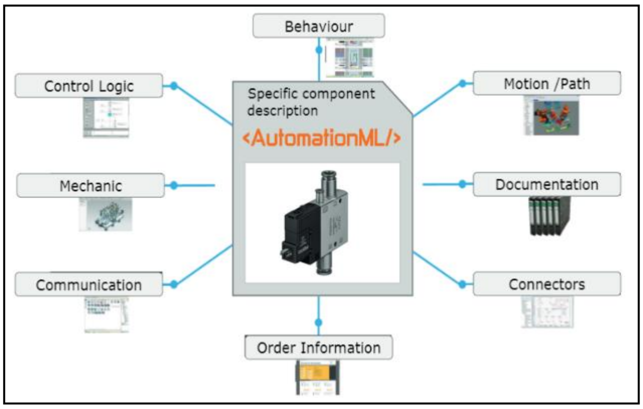

Fig 1. Aspects of an automation component or production system [3]

An Automated production system or plant consists of a number of subsystems and subcomponents that interact in various ways and can form hierarchies. When designing these systems, various factors must be considered. Different engineering disciplines require different but potentially interrelated information even on a single automation component, such as functional engineering, mechanical planning, or electrical planning [3]. Figure 1 shows the different types of information a component of AutomationML can contain.

The rest of the paper is organized as follows: section II introduces about the AutomationML. Section III demonstrates about the AutomationML component, its stakeholders, use cases, sub-modelling of its components and its logic representation. Section IV details how the AutomationML component changes the production systems Engineering. Section V outlines the summary of the paper.

II. BACKGROUND

AutomationML:

To Understand AutomationML Component we need to have some basic knowledge about AutomationML. AutomationML main strength is its representation of interconnected information, even when it is from different domains (interdisciplinary).

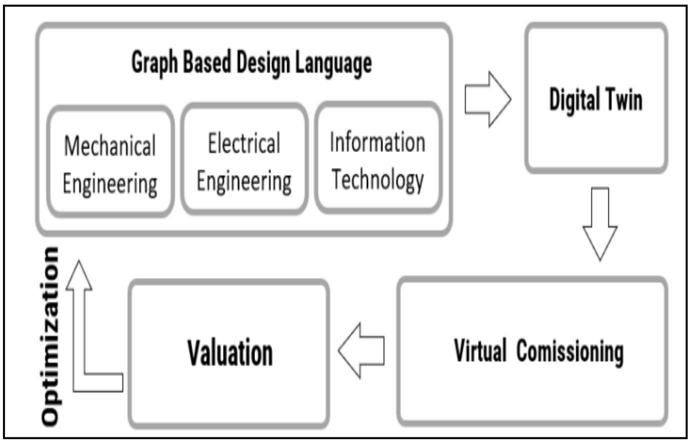

Fig 2. Iterative Cycle of Digital Production Optimization.[4]

AutomationML consists of cycles that start with Graph-based design language, Digital Twin, Virtual Commissioning, and valuation. Graph-based design language includes Mechanical, Electrical, and Information Technology collaboration to give optimum input to the digital twin. The concept of digital twins is complex, and there is no unified platform for representing both the physical characteristics and the control of the plants. Now data will have to be passed from one department to another and often converted, which will be time-consuming and may lead to data loss at any time [4]. As a prerequisite to calculating a machine's energy consumption using a digital twin, the machine needs to be accurately represented using the functions of a virtual commissioning model. Now comes the valuation part where the processing time, material flow, energy efficiency, and profitability are taken into account and optimized the parameters according to the requirement. AutomationML uses a common data format to simplify the engineering of production systems by offering a consistent format that can be utilized from the initial design of a plant through the final system commissioning. Hence, AutomationML must be able to store a wide range of logic information for a production system or a particular component.

III. AUTOMATIONML COMPONENT

AutomationML Components are objects that describe automation components or systems. The automation component can be either a type or instance model. Furthermore, there are no subcomponents of the automation component. AutomationML Components can be stored as SystemUnitClasses or InternalElements[5]. Automated components are defined in multiple engineering phases of the design of production systems utilizing various engineering tools. Engineering activities use specialized tools, which will significantly impact the information on automation components.

A. *Stake holders:*

When considering the AML Component Model and its life cycle, different stakeholders must be considered [3]. The first is the standardization organization that defines and publishes the model and makes it available. AML Component description is defined by AutomationML association, which has defined a Meta Model for component description. As part of this Meta Model, you will find AML role classes and specifications on how to describe AutomationML components using them.

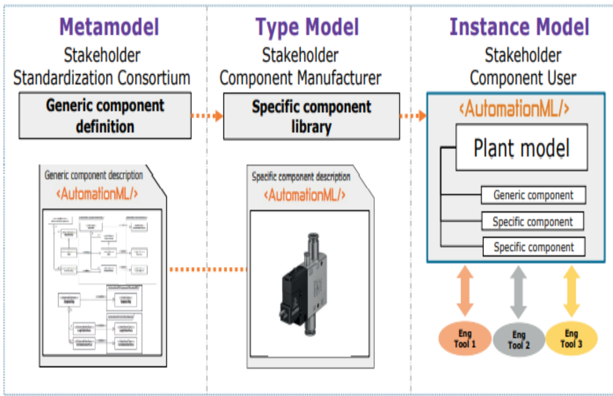

Fig 3. Stakeholder of Automation component [3]

The second stakeholder is component manufacturers who apply the AutomationML Component Model to describe their automation components and make them available as catalogues. Typically, this is done via CAEX SystemUnitClasses and libraries that define types of components. Manufacturers of component products could be companies that sell typical automation components such as sensors or actuators, or they could be companies that provide more complex automation systems such as complete welding robots and coil automobiles. Complex automation systems can be assembled from different subcomponents. The description of such automation systems in AutomationML is defined as AutomationML Composite Component. AutomationML SystemUnitClass is used to store and exchange these types of models of automation components

B. *Use Cases:*

Depending on the use case within the engineering chain, these tools will generate or consume component-related engineering information. some relevant used cases for the exchange of automation components:

1) Materials Management and Warehousing

A bill of materials is one result of an engineering workflow, which is used to order spare and wear parts for stores. Each part must be identified properly. Therefore, part numbers or order numbers must exist in order to locate existing parts. Standardized catalogue information, including all relevant documents for planning, engineering, maintenance, commissioning and decommissioning, is necessary. In an advanced engineering scenario, all engineering tools participating in the process can refer to the same part, which is required for effective data processing at the end of an engineering process.

2) Component Description as Base for xCAD:

This use case presents three cases of how data from the AutomationML Component description given in AutomationML files by Component Manufacturers could be used in Component Users' engineering tools. These 3 cases are:

- Electrical Engineering and software design
- Mechanical Engineering
- Fluidic Engineering

3) Simulation and Virtual Commissioning:

In Virtual Commissioning (VC), the control code is validated by using a simulated process environment instead of the actual machines or plants themselves. As a result, the behaviour of the overall system can be tested in virtual standard and extreme situations before it is deployed to the controller hardware, resulting in the need for multiple tests.

4) Maintenance and Documentation:

When the production system is established, it is used in the value creation process. In this way, the system components experience wear and tear. In order to prevent or minimize system failures, the system user needs to perform production system maintenance. An important requirement for successful and efficient maintenance is the availability of detailed and up-to-date system documentation that covers all relevant details of the system design and operation. The description of the components must address all of these aspects.

C. *Sub-Modelling of Automation Components:*

AutomationML Component must map or integrate information from different components of an automation system. There are two mechanisms for doing this:

a) First, the automation component's information is stored in its attributes.

b) Second, sub-models are modelled as internal elements or linked via the internal elements.

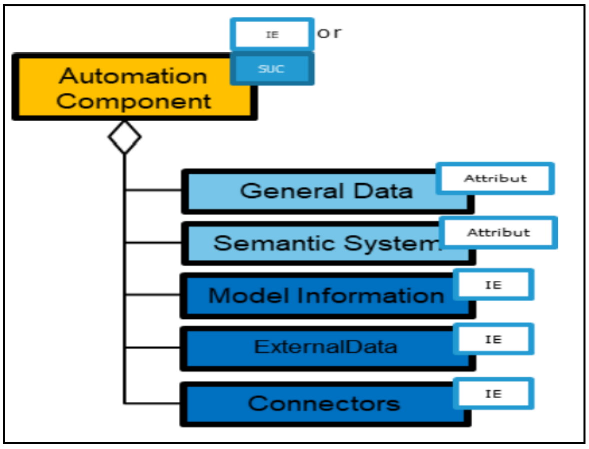

Fig 4. Information and sub-model in AutomationML [5]

The following categories can be distinguished as:

1) General Data: This part incorporates component identification and classification data from the vendor, like the product identification code, ordering information, serial number, version number, other technical information. All this information is mapped to attributes of the root of an AutomationML Component model.

2) External Data: This includes, for example, the documentation of the automation component and a picture of the component. The external data are linked to the AutomationML Component via an ExternalInterfaces that belong to a child InternalElement of the AutomationML Component root.

3) Modern Information: comprises different kinds of models representing the automation component. Examples for such models are:

a) Functional Data
b) Simulation models
c) 2D and 3D models
d) Kinematic models

4) Connectors: Connectors The connectors describe information to all logic, electric, pneumatic, hydraulic and other interfaces of the component.

D. *AutomationML Component Logic Representation:*

Automation systems and components are resources that can perform a certain task or process in an automated system. Control of automation components is often provided by one or more points in the process. The description of a logic representation and simulation of automation components can be described by three different standardized logic models. They differ in the way they are integrated and used within the AutomationML Component and the libraries.

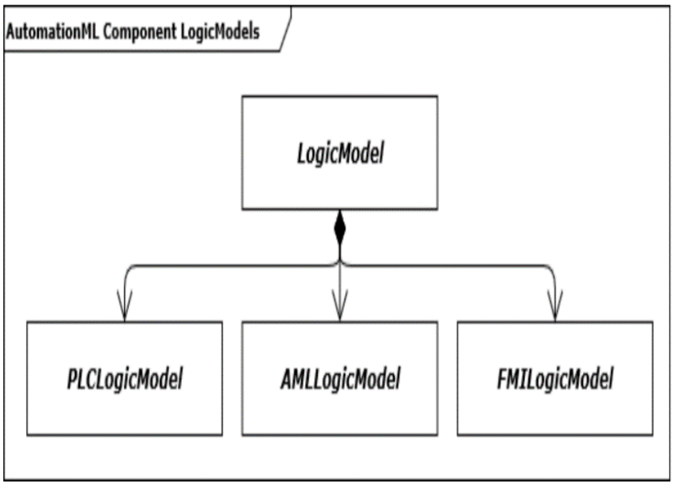

Fig 5. Logic Models [5]

The three models are:

1) PLCLogic Model that defines logic description on base of [IEC61131-10:2019].

2) AMLLogic Model that defines logic description and integration into AutomationML on base of AutomationML [WP-Part4:2018].

3) FMILogic Model that defines logic description on base of the FMI standard [FMI:2019].

The three possible models shall support different use cases for logics of AutomationML Components that could be realized by any of them and not be restricted to a certain type of logic representation. These use cases for the model integration are in general the description of:

a) Behaviour models
b) Simulation models
c) Functions
d) Sequences or sequence elements
e) Skill logic models

IV. ROLE OF AUTOMATIONML COMPONENT IN PRODUCTION SYSTEM

AutomationML is designed as a flexible, prototype-based language that can be used to represent the full spectrum of engineering artifacts, and for integrating engineering data exchange between heterogeneous tools. An AML-based production system may utilize reusable libraries containing prototypical hardware and software elements (such as screwdrivers or PLC controllers)[6].

Within a complex production system, mechatronic production system components (consisting of automation components) perform a variety of interactions with one another. Designing production systems requires a variety of engineering disciplines, including functional, mechanical, electrical, control, and HMI engineering. These disciplines require specific information about automation components. It presents a meta-model for an AutomationML Component to describe such automation components and production systems on different levels. Within these meta models, functional roles are used to identify information related to aspects using role classes within AutomationML.

Within AutomationML Components, another aspect is the relation in which the automation component can be placed. In order to model this, interfaces and connectors of automation components need to be described in order to interlink them as well as internal relationships between component aspects and external information.

The lifecycle of production systems encompasses various phases that can benefit from the use of consistent component descriptions by providing consistent information to the applied tool chains [5].

Few tools that are involved in this process may be [5]:

- Plant planning tools
- Mechanical engineering tools (MCAD)
- Electrical engineering tools (ECAD)
- PLC programming tools
- Robot programming tools
- HMI programming tools
- OPC UA system configuration tools
- Device configuration tools
- Bus configuration tools
- Simulation tool
- SCADA systems
- Virtual commissioning tools
- Documentation tools
- Communication system security tools
- Communication system configuration tools
- Communication system management tools
- Communication system diagnosis tools

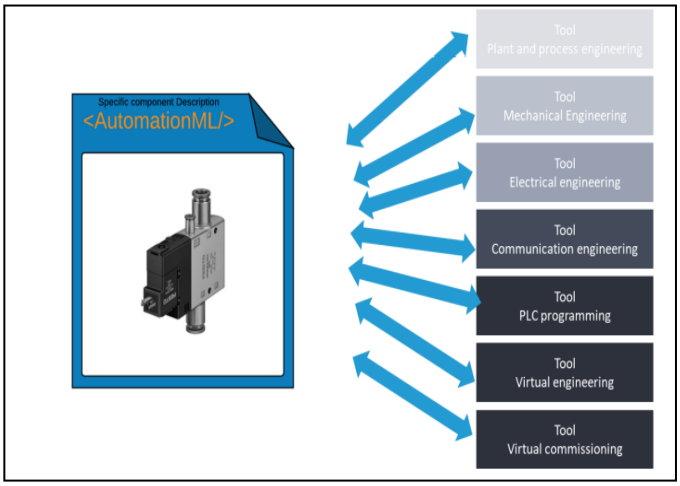

Fig 6. Overview of tool use for AutomationML Components [5]

When creating the system development phase of the production system, for example, the overall resource structure, mechanics, electronic structure, and software are designed. Plant and process planning tools, CAD tools, programming tools, and configuration tools (especially for communication systems) are used during this phase.

Coming to the use cases, Different engineering activities in the production system chain are dependent on component-related information. Automation components can be defined in the individual engineering phases of production systems utilizing different engineering tools. This results in the creation of automation component information. It should then be applied during the detailed design of the devices as well as when they are being commissioned. Different engineering activities require specialized engineering tools, which will be relevant to the automation component information. From the relevant use cases, we are defining Virtual Commissioning, Maintenance and Documentation for production systems.

Defining Virtual Commissioning in terms of the production system. In order to achieve efficient VC of complex systems, the simulation model should be modular since it enables the reuse of components. This is a practical approach for providing a simulation model based on a corresponding mechatronic component since it relates to the type of equipment. Developers of simulation models for components need a deep understanding of the behaviour of the components. Thus, the manufacturer of the component becomes also a candidate for the development of the corresponding simulation model.

Coming to Maintenance and Documentation System, normally, production system documentation begins after the engineering phase, and summarizes all engineering information, including, but not limited to, function design, mechanical engineering, electrical engineering, communication system engineering, and control programming. Therefore, the engineering tools need to provide the documentation tool with their results. Documentation is carried out during the production system commissioning by updating engineering results based on changes made during the physical realization of the production system and by incorporating information on the labelling of system components (such as wire marking or printed reference signs). The documentation tool must, therefore, receive results from the related commissioning tools. Documentation is also carried out during the production system use phase. Replacement of production system components and their impact on mechanical, electrical, control, etc. construction of the production system shall be documented here to ensure an as-is documentation. Thus, engineering, commissioning, and maintenance tools must provide their results to the documentation tool.

V. SUMMARY

In this paper, we surveyed AutomationML and AutomationML Component and we can say that with AutomationML, we can effectively model today's engineering aspects as well as future engineering aspects. AutomationML Component is the first approach to integrating all relevant engineering information in one model and making it available. The tool chains use the information of the AutomationML component to improve the lifecycle of a production system which depends upon the use cases which we have described in this paper.

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Implementation of Module Type Package in Production System Engineering

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***Abstract*—The modularization of production systems is viewed as a potential strategy to meet the growing industry requirements in terms of flexibility and changing customer needs. The present study assesses the needs of the current production system engineering, and how modularization of production plants can be the breakthrough approach in fulfilling those needs. A proposal has been devised to address the present difficulties in the implementation of modular plants, particularly in their integration. The Module Type Package (MTP) is a concept for quickly integrating a module's automation system into the higher-level process control system. This paper describes the various methods to implement MTP and to integrate MTP into Production Systems.**

Keywords—Modularization, Module Type Package, Integration, Production system engineering.

ABBREVIATIONS AND ACRONYMS

Table I. Abbreviations Table

Serial No.	Name	Abbreviated form
1	German User Association for Automation in Process Industries	NAMUR
2	Decentralized Intelligence for Modular Assets	DIMA
3	German Electrical and Electronic Manufacturers' Association	ZVEI
4	Process Equipment Assembly	PEA
5	Programmable Logic Controller	PLC
6	Process Control Element	PCE
7	OPC Unified Architecture	OPC UA
8	Process Control System	PCS
9	Service-Oriented Architecture	SOA
10	Human-Machine Interfaces	HMI
11	Verein Deutscher Ingenieure	VDI
12	Verband Deutscher Elektrotechniker	VDE

I. Introduction

Rapidly changing customer needs, increased demand for customized goods, customer-specific specialization and flexibility are the main reasons for shortening the product life cycles. These reasons are impacting the market maturity which in return is a huge problem for the current production systems to adapt.

We must ensure that a production system has to tackle such volatile markets and should utilize the advantages of both continuous production and batch production so that it could be efficient, versatile and Flexible enough. Modularization is a promising technique that aims to provide Interoperability, Decentralization, Virtualization, and Service Orientation to pave the way for future production systems. An EU research initiative called F3 Factory (Flexible, Fast, and Future) created the foundation for this concept.

Modularization ensures the plug and produce process, thus helping in reducing the time to market. The initial capital required may be high but cost benefits can be seen when we compare the time between the first idea of a product and its production. Modularization acts as a bridge for the transformation of current production systems to futuristic ones. In future, modularization will easily coupe up with the rapidly changing technology and technological advancements with comparably lowered engineering and automation costs for the future updates.

As the conventional process systems are incapable of meeting the requirements of fast-growing customized markets and production facilities, modularisation has been considered as a key factor in the process systems.

Before diving into Modularization, Module Type Package and their integration, we will investigate different existing integration technologies.

1) GSD/GSDML: The GSD (Generic Station Description) describes the hierarchical structure of a field device one-dimensionally XML-based documents use the model of a hierarchical device as accurately as possible with the advent of GSDML (General Station Description Markup Language). GSDML allows to create module and submodule relationships for modular field devices [1].

2) EDD: The Electronic Device Description (EDD) provides a clear description of attributes. It contains information on the field device's behaviour which can be observed externally. This information grabs the device-related resources and functionality. The EDD Language (EDDL), which is defined in IEC 61804-3, allows for the description of data (parameters), communication (addressing), and the structure of handling and operations (calibration) [1].

3) FDI: Since 2007, the EDDL collaboration team along with the FDT group are working together to provide a standard solution for Field Device Integration (FDI). FDI enables device integration and it is independent of the surrounding user systems utilized. The FDI packages that contain the information required for the integration is sent by the manufacturer [1].

Although there are many Field devices available for device description and are nearly equivalent to module descriptions when transferring information is compared. Several standardized, proprietary description formats for automation used in the industry have been investigated [2].

Results show that the description format FDI is only partially qualified to describe all necessary information for integrating a module into a high-level PCS. So, to integrate the module into the PCS more effectively, a description data model called MTP has been developed. MTP contains all the necessary information of the module required for its integration. The server used for communication between the modules and the Process Management Level (PML) is OPC UA [3].

The rest of the paper envisages the following: It starts with Section II explaining the concept of Modularization, its goals and advantages. Section III enlightens about the MTP and MTP language Based on the above two sections, Section IV demonstrates the integration of modules into the POL using the OPC UA server. Section V, VI explains the required conditions and criteria for the successful implementation of MTP. Section VII envisages the recent developments and ends with a summary.

II. Modularization

Manufacturing and process industries have evolved separately in the past due to the difference in product characteristics. The products in the process industry are shapeless fluids or bulk materials, whereas products in manufacturing are solid objects or assemblies of such items. Consequently, there are significant differences in the processing/machining of those products. In processing, products are changed by chemical or physical transformation, which is often sensitive to timings and sequential order. In machining, products are changed by modifying the shape, surface or material properties or by joining or separating them [4].

The production plants in the process industry have always been designed in a monolithic fashion, while in the manufacturing industry the modularization of packaging cells has already been well-established [5].

Modularization of process and manufacturing facilities is now increasingly being seen as a game-changing technology for meeting the contemporary process industry's growing flexibility demands. Modularization of process plants helps in the establishment of a flexible production environment in the current situation, which includes shorter product lifecycles and high-volatile markets [7].

A modular process plant is made up of several process modules that contain encapsulated equipment and apparatuses as well as process controls and instrumentation. As a result, every module can be called PEA, which encapsulates and offers as a service for at least one process function [6,8].

A. Goal of Modularization

Modularization aims to significantly decrease the design effort by reusing standard designing solutions of modules in combination. The modularization of production plants in the process industry delivers its effects in 3 distinct areas: Time-to-market, changeability in the production volume and variety, and mobility. Firstly, time-to-market should be reduced by a faster planning process, due to the reuse of information and due to the use of already pre-engineered modules as units. Also, time savings could be achieved because of well-known constructions of recurring modules. The changeability of the production process in terms of product output volume can be increased by a numbering up (or down) of modules instead of a scale-up. The flexibility of the plant may be achieved by changing the selections, arrangements, and different combinations of modules, resulting in a flexible modular plant [9].

B. Advantages and Functioning

The module layer and the orchestration layer are the two layers of the modular automation system. The module layer is a small controller that executes the logic of a single module, while the latter, the orchestration layer merges process modules into one process plant. In comparison to traditional plants, the modules in modular process facilities are not orchestrated using tags. Every module has a collection of services that are encapsulated process operations that may be coordinated from a supervisory control system.

Every service describes a process function included in the manufacturing in the proper sequence, the integrated modules will work together to meet the plant's requirements. Engineering is also done differently. First, the module types must be engineered before they can be integrated into the supervisory system. Also, because instances may be created, the engineering work for the plant can be greatly reduced by reusing modules of the same kind [3].

As per the NAMUR Recommendation NE 148 guidelines, there are two sorts of modules that are referred. A module of type one without a PLC is useful for implementing basic process functions. The second type can be utilized for more complex jobs which employ a PLC to control the execution of one or more process functions within the module [10]. But the goal of an increase in manufacturing and production flexibility can be achieved only if the process of integrating the modules into the production system is simple and effective. So, for the modularization to advance further these integration efforts, such as the human-machine interface, unique solutions and reprogramming of the control code must be considered and worked upon. The concept proposes a mechanism to quickly integrate the automation system of a module into a higher-level process control system [9].

III. Module Type Package (MTP)

To meet the growing demands of modularization and its fast implementation and integration, NAMUR produced a requirement specification for the automation of modular process plants, which emphasized the need for easy module integration. The DIMA research project was established in 2013 to develop a mechanism for introducing an information carrier file based data model known as MTP, described in Fig. 1, for modularization to make integration easier and faster [9].

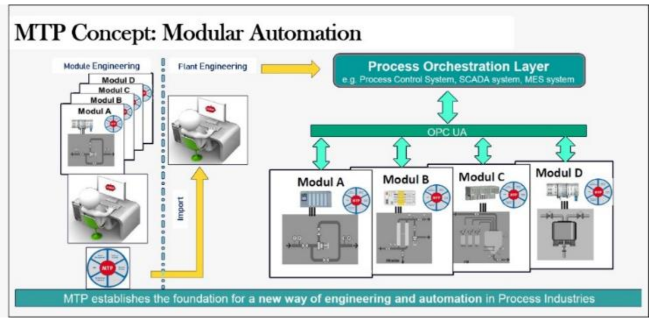

Fig. 1. Concept of Modular Automation [11]

In 2014, the NAMUR, in collaboration with the ZVEI and the DIMA, agreed to concretize and standardize the idea. They were joined by WAGO kontakttechnik Gmbh, Dresden Technical University, and Helmut Schmidt University Hamburg [12,13]. In total, more than 25 industry representatives were involved in developing the MTP's content and structural guidelines for the MTP and the groups are now working on a set of rules for modular process plant automation, including MTP content specification and modelling, with the long-term goal of obtaining an international IEC standard [9].

Presently, the standard VDI/VDE/NAMUR 2658 deals with the specification of an interface and its semantic description of modular automation systems. The MTP helps to identify the functional interface and communication interfaces of a modular automation system [3].

Plant-independent module engineering and plant-specific integration engineering (Network engineering, Implementation of cross-module procedure control) are two types of engineering that determine how production system plants are designed as shown in Fig. 2. Module Type Package should contain all of the information created during module engineering that is required for integration and may thus be regarded as the module's driver file. It is vital to save the information required for integrating that module into the Backbone.

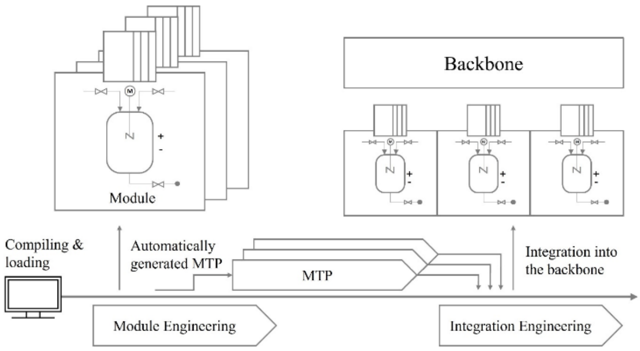

Fig. 2. Basic Structure of Modules and MTP [9]

Modular process automation systems consist of PLCs in the modules and the intelligence of each module is embedded within the logic programming of the PLCs. Each module is programmatically linked to its preceding and succeeding modules. Furthermore, all modules are connected to the Backbone, which supplies and disposes of the necessary media, energy, and communication infrastructure [9].

A. MTP Language

The primary criterion for the modelling language use is, it must be machine-understandable for automated output and input. It was decided to adopt an XML-based language. Also, the engineering exchange format AutomationML (AML), which was Internationally Standardized in IEC 62714, was chosen as an appropriate descriptive language for modelling and documenting MTP information. AML also uses a multi-library method to describe a huge number of different elements. This has various advantages, not just in terms of information modelling, but also in terms of MTP adoption for international standardization [9].

The information generated throughout the module-engineering process is required during the integration of a module into a plant. MTP should provide an appropriate digital representation of the module which should include the following aspects, process functions, data acquisition, process control, human-machine interfaces (HMI), data diagnosis and maintenance, alarm functions and supervision [10].

As a result, these elements are treated as independent objects within the MTP. UML class diagrams are used to explain and depict the MTP's present basic principles. Fig. 3 shows UML class diagrams of service description while Fig. 4 illustrates the same for HMI description.

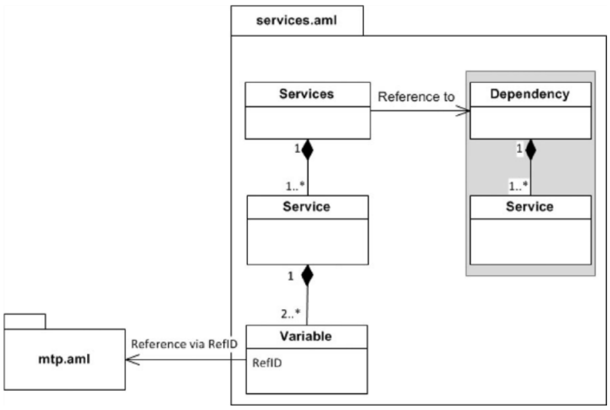

Fig. 3. Class diagram of the service description [9]

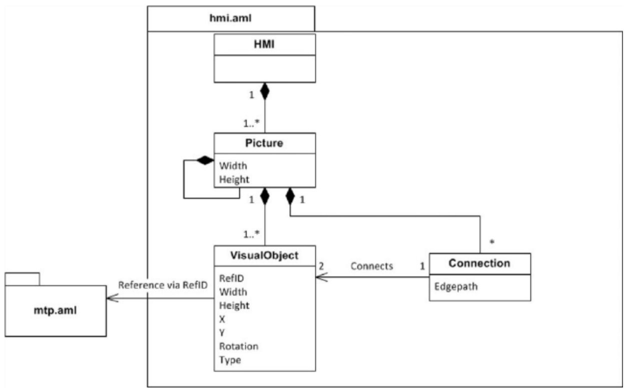

Fig. 4. Class diagram of HMI description [9]

B. MTP State-based Control Diagram

The state-based control diagram of MTP and manifestation is shown in Fig. 5, it covers the three major aspects such as

- Communication: communication technology supported by the module.
- Services offered by the module HMI with the navigation hierarchy within the module and references to the operating screen descriptions.
- PCE provides information on all functions and variables that should be communicated to coordinate and integrate the control and operation layer [9].

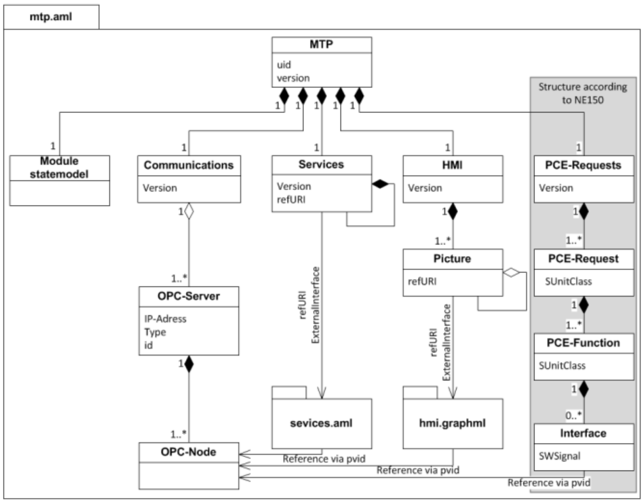

Fig. 5. MTP State-Based Control diagram [9]

IV. Controlling and Integration of Modules

A. PCS

Considering that each module comes with its own PLC, Module engineering should make use of a variety of engineering techniques and digital data models to encapsulate the process functionality of modules that employ decentralized modularization.

The decentralized Modularization enables the establishment of flexible modular production automation utilizes a PCS technology to which the modules send their engineering process as measurable empirical services. In this controller, all of the various individual processes are implemented. So, the MTPs can even be created automatically by the module engineering tool and integrated into the PCS automatically.

Typical functions of a PCS are mentioned as:

- HMI provision to influence the technical process
- Control and adjustment of the technical process
- Provision of recipe/batch-interface
- Supervision and alarm management
- Archiving of parameters and process data
- Evaluation of data
- Recording of signals [9]

B. OPC UA

The NAMUR released guideline NE148, which defines standards for process plant modularization and module integration into a process control system PCS. This scenario will only become a reality if module integration can be done quickly and efficiently in a plug-and-produce way.

OPC Unified Architecture (OPC UA) is regarded as a fundamental technology for this scenario in Industry 4.0 reference architecture. OPC UA is a medium between the modules and their Controlling systems which generally transforms AML and GraphML data into a more capable form. OPC UA is considered a key technology because of its capabilities for semantic description and online integration via information modelling [14].

1) *Advantages of OPC UA*

OPC UA is platform-independent and is extendable to any system with which it is integrated. The ability to model the data semantically makes it more user friendly. The MTP automationML to OPC UA transition can be done systematically at different levels as shown in Fig. 6.

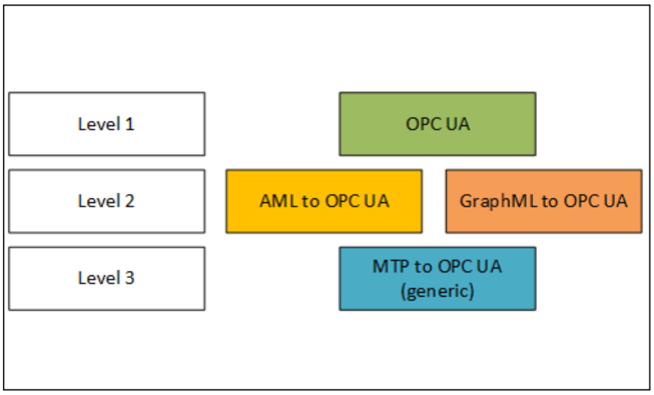

Fig. 6. OPC UA representation from MTP indifferent levels [14]

C. SOA

The modularization, module functions and their communication can be carried out by SOA. SOA results from the orchestration and parameterization of various services from the PCS. The benefit of SOA is that it may be used to organize complex networks that require interoperability. It's also scalable and adaptable.

SOA refers to a collection of black-box components that deliver services through an interface, as depicted in Fig. 7, which is executed using communication services. The modules are represented by the black box components, which perform process functions by encapsulating services [15].

2) *General approaches in SOA:*

a) OASIS approach: It is the mechanism to provide the access to one or more capabilities. It defines three fundamental concepts involved namely, visibility, interaction, real-world effect.

b) SOCRADES approach: It defines four fundamental topics which include, Wireless sensor/actuator network, Enterprise integration and System engineering and management along with Service-oriented architecture.

c) Process control with high-level Petri nets: It describes the following relations which are:

- Parallelism
- Concurrency
- Synchronization
- Memorizing
- Monitoring
- Supervising
- Resource sharing

d) Implementation with function blocks [15]

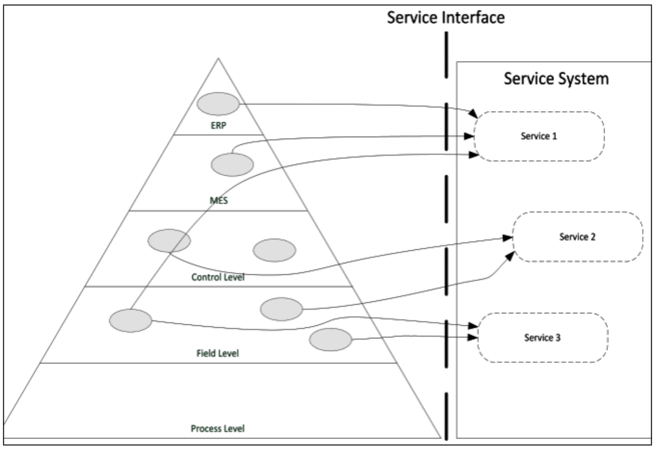

Fig. 7. Service System and Interface in SOA [15]

V. Criteria of Modular Process Automation

The following section describes some of the conditions that are needed to be fulfilled to be acceptable for modular process automation. The requirements are based on the control and communication aspect of process automation [15].

A. Availability of a Superior Control System

A superior Control system is needed to control the modules and their services. A cooperative control between the modules may not be possible by themselves but overall inter control of modules is required [15].

B. Implementation of Intelligent Modules

Intelligent modules are required as each module is equipped with a PLC. PLC includes all the required services and functions of all the devices in the module [15].

VI. Conditions for the Success of MTP

To successfully implement MTP in a production plant, the below mentioned conditions need to be met:

- The essential demand from customers, who should include delivery of an MTP in their specification sheet for module and package unit providers. Even if total modularization is not yet attainable, these modules will remain flexible in the long run and will aid in the speeding up of future plant construction projects.
- The addition of MTP functionality to existing process control systems to ensure that existing plants also benefit from the new option of integrating package units
- The internationalization of the standard, which may have been driven by the German organizations NAMUR, ZVEI and VDMA, will ultimately be used worldwide by the globally active process industry companies involved.
- The ability to operate and observe, all of which cannot be captured using current device descriptions

VII. Recent Developments And Summary

In October 2019, a New Work Item Proposal (NWIP) was submitted to the International Electrotechnical Commission (IEC) aiming to establish the MTP concept as the International Standard IEC63280. A change in responsibility announced at the 2021 NAMUR general meeting will also be conclusive to internationalization. The new “MTP host” is the PROFIBUS user organization, which will take care of further standardization in future at the international level.

Modular production with standardized interfaces will play an important role in Industry 4.0. With its quick integration property, it can shorten the time-to-market, increase production flexibility and reduce investment risks. The manufacturer independent Module Type Package (MTP) will play a key role in this.

The current research projects and the pilot projects are showing fruitful outcomes. Whether it becomes a market success will depend on the demand among the users. It will be a win-win situation for both module manufacturers and plant operators.

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A survey on XML and its role for data exchange in Engineering Organisations

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***Abstract*—In this paper, we inspect various annotation and markup languages diving into the details of XML, its basic properties and applications in the field of data exchange with a special focus on its role in Engineering organisations in different aspects like design, production, process and business analysis.**

Keywords: markup, XML, PML, PPR, simulation model

I. Introduction

Computers, as vital as they are in electronics design, have all too frequently failed to support long-term business objectives in this setting. To date, little effort has been made to comprehensively capture and reuse the content of engineering calculations whether data, formulae, or variables in project management, reporting, and regulatory compliance. Organizations frequently lose sight of engineering assumptions and the data that contributed to them. Traceability and accountability have largely been left to paper systems or tracking software that operates outside of the engineering process. But what if there was a way to include reusability and accountability right into the labor that generates the design? In other words, if the numbers used to generate the ultimate outcome of an engineering calculation are self-verifying, then design and responsibility merge into one. The engineer is making the work recordable, traceable, manageable, and reliable by conducting the design work [3].

Integrating responsibility and design into the same process will not only raise the productivity of the individual engineer, but would also improve the general efficiency of the business. This method would allow for more efficient decentralization of product development and manufacturing, shorter time to market, more effective reuse of ideas and policies, better standard implementation, and more effective compliance. Information must flow readily, logically, and instantly among different types of systems to support this dispersed collaboration. Markup languages make this possible. Since its inception in 1996, the momentum behind markup language has increased at an astounding rate. The engineering community, on the other hand, is only now beginning to recognize its potential benefits.

II. Annotation and Markup languages:

Annotation is merely the process of adding additional material for a variety of objectives, such as commentary, viewpoint interpretation, or supplementary description. Annotation has long been used in engineering practice to facilitate communication; for example, engineers may discuss a product face-to-face by annotating a design drawing, or they may transmit an annotated drawing of a product to teammates (an example is shown in figure 1) [2]

There are three general categories of electronic markup, articulated in Coombs, Renear and DeRose (1987), and Bray (2003) [5].

A. Presentational markup

Traditional word-processing systems use this type of markup: binary codes inserted within document text to provide the WYSIWYG (”what you see is what you get”) effect. Such markup is typically hidden from human users, including authors and editors. Underlying procedural and/or descriptive markup is used, but it is converted to ”present” to the user as geometric arrangements of type.

B. Procedural markup

Markup is text that is contained with instructions for programs to process. Troff, TeX, and Markdown are well-known examples. It is anticipated that software will process the text sequentially from start to finish, following the instructions as they are encountered. The author frequently edits such material with the markup visible and directly controlled. Popular procedural markup systems typically include programming tools, particularly macros, that enable complex sets of instructions to be executed by a single name (and perhaps a few parameters). This is faster, less error-prone, and easier to maintain than repeating the same or similar instructions in multiple locations.

C. Descriptive markup

Markup is specifically used to label parts of the document for what they are, rather than how they should be processed. Well-known systems that provide many such labels include LaTeX, HTML, and XML. The objective is to decouple the structure of the document from any particular treatment or rendition of it. Such markup is often described as ”semantic”. An example of a descriptive markup would be HTML’s cite tag, which is used to label a citation. Descriptive markup

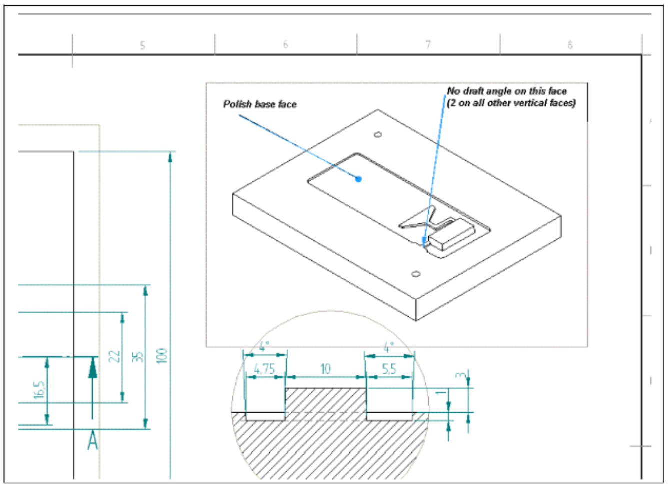

Fig. 1. An example of annotation [2]

— sometimes called logical markup or conceptual markup encourages authors to write in a way that describes the material conceptually, rather than visually.

There is considerable blurring of the lines between the types of markup. In modern word-processing systems, presentational markup is often saved in descriptive-markup-oriented systems such as XML, and then processed procedurally by implementations. The programming in procedural-markup systems, such as TeX, may be used to create higher-level markup systems that are more descriptive, such as LaTeX.

The names of the most popular languages usually end with Markup Language and so are abbreviated as something-ML [3]: for example,

- HTML – Hypertext Markup Language
- KML – Keyhole Markup Language
- MathML – Mathematical Markup Language
- SGML – Standard Generalized Markup Language
- XHTML – eXtensible Hypertext Markup Language
- XML – eXtensible Markup Language

Table 1 summarizes the core markup languages [2]. In this paper, we will focus on XML since, as the name implies, it is extensible: that is, it can be adapted to demands and focus when marking up texts.

III. Basics of XML

The acronym eXtensible Markup Language, or XML, should be recognizable by now. Although many people understand the basic notions of XML — allowing disparate platforms to communicate and software to be portable — it's critical to understand how to utilize it in engineering solutions. Extensible Markup Language (XML) is a basic text-based format used to describe well-structured data such as documents, books, configuration, transitions, and much more. It is shortened to XML and is one of the most widely used formats in the world. XML, like HTML, is a self-descriptive markup language. Its main purpose is to store and convey data [1].

TABLE I
Summary of the Core Markup Languages [2]

Language	Based on	Developer	Initial release	Major applications
Generalized Mark-up Language (GML)	–	IBM	1960s	Document
Standard Generalized Mark-up Language (SGML)	GML	ISO	1986	Document
HyperText Markup Language (HTML)	SGML	W3C & WHATWG	1991	The World Wide Web
eXtensible Markup Language (XML)	SGML	W3C	1996	Arbitrary data structures
Dimensional Mark-up Language (DML)	XML	NIST	–	CAM/CNC
Product Information Mark-up Language (PIML)	XML	Lee et al.	2005	PLM
eXtensible Rule Mark-up Language (XRML)	XML	Kang and Lee	1998	Web information
Motion Capture Mark-up Language (MCML)	XML	Chung and Lee	2003	Motion capture data
Scalable Vector Graphics (SVG)	XML	W3C	2001	2D graphics
Vector Markup Language (VML)	XML	Autodesk, Macromedia, Microsoft, Visio	1998	Vector information together with additional markup
Precision Graphics Mark-up Language (PGML)	XML	Adobe Systems, IBM, Netscape, Sun Microsystems	–	Vector graphics
X3D (eXtensible 3D)	XML/ VRML	W3C/ISO	–	3D graphics
3D XML	XML	Dassault Systemes	–	3D data
PLM XML	XML	UGS.	–	PLM information
Description Framework(RDF)		W3C	1999	Web resources
Web Ontology Language (OWL)	RDF/ XML	W3C	2002	Web ontology language
Commerce XML (cXML)	XML	more than 40 companies	1999	e-commerce
Simple Object Access Protocol (SOAP)	XML	W3C/ Microsoft, IBM,DevelopMentor	2003	Web service
Web Service Description Language(WSDL)	XML	W3C /IBM, Microsoft, Ariba)	2000	Web services
Remote Procedure Calls (XML-RPC)	XML	Dave Winer of UserLand Software and Microsoft	1998	Internet

It is the most frequently used format for sharing structured information today, both locally and across networks, between programs, between individuals, and between computers and people. It is conceivable due to its adaptability, and the key benefits are that it is self-describing, expandable, redundant, simply transformable, and, most significantly, platform independent. The potential impact of XML on company productivity will be comparable to the impact of the relational database management system (RDBMS) in the business world more than 20 years ago. XML promotes productivity in technical cooperation by enabling information to be communicated more effectively, just as RDBMS generated new business prospects by enhancing the way users viewed, managed, and eventually used different types of data. Because XML is a meta language, it allows businesses to develop their own bespoke descriptions for communicating information in their area. At the same time, it enables enterprises to transform unstructured data into useful, organized content that can be easily shared with others in the same field, regardless of computing environment.

In this approach, XML may provide the most significant advance in engineering collaboration to date. It will eventually provide meaning and traceability to every product design, as well as every engineering process and value underpinning it, enabling on-time product development, product quality, regulatory compliance, and auditability. Calculation management is a new best practice for collecting engineering processes and values to make product development more manageable in general.

XML is widely utilized today and is used in practically every field. It is the foundation of many standards, including the University Business Language (UBL), Universal Plug and Play (UPnP), which is used for home electronics, word processing formats such as ODF and OOXML, graphics formats such as SVG, and communication with XMLRPC and web services. It is also supported by computer programming languages and databases, ranging from big servers to telephones. If you double-click on any program on your phone, an XML message is likely to be transmitted from your phone to the server or to another phone. When you take your car in for service, the engine's processing unit will transmit an XML file to the mechanic's diagnostic systems. It is the age of XML [1].

IV. APPLICATIONS OF XML

The four primary XML implementations are as follows [4]:

A. Publication

Using an XSLT stylesheet, database content may be translated to XML and then to HTML. Complex websites, as well as print media such as PDF files, can be created using this technology. Information does not need to be kept in many formats any longer (i.e. RTF, DOC, PDF, HTML). Content can be stored in the neutral XML format, and subsequently brochures, websites, or datalists can be created using appropriate layout style sheets and transformations.

B. Interaction

XML can be used to access and change data in real time. This man to machine contact is typically accomplished through the use of a web browser.

C. Integration

Homogeneous and heterogeneous apps can be interconnected using XML. XML is used to specify data, interfaces, and protocols in this situation. This machine-to-machine connection aids in the integration of relational databases (i.e. by importing and exporting different formats).

D. Transaction

XML facilitates transaction processing in applications such as online marketplaces, supply chain management, and e-procurement systems.

V. ROLE OF XML BASED DATA EXCHANGE IN ENGINEERING ORGANISATIONS

The application of XML for Data Exchange for Engineering organisations has a very wide scope. This survey covers a range of such applications.

A. Capital facility industries

As a joint development effort by Fiatech, Hydraulic Institute (HI), DIPPR (Design Institute for Physical Properties), Alar Engineering Software, Inc. and Protesoft Corporation, a capital facilities industry XML (cfiXML) schema model was developed to facilitate exchange of equipment data such as items, relevant engineering and material documents along the supply chain and enhance interoperability solutions in the industry. The major purpose cfiXML model serves is acting as a standard data exchange language between the stakeholders in the industry that is compatible with different software applications. (Mark Palmer (NIST), 2012) [6]. In figure 2, the wide range of equipment data that can be stored and simplified has been indicated

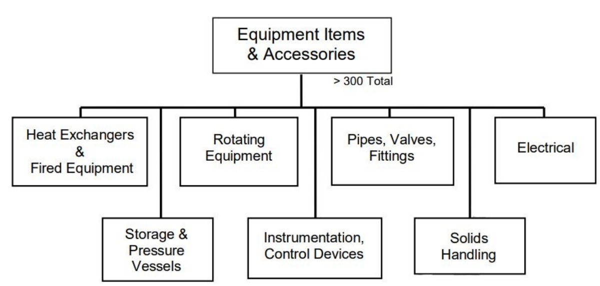

Fig. 2. Range of equipment data [6]

B. Virtual enterprises

A virtual enterprise is a global platform for companies with aligning business goals to share information about their core resources, experiences, competencies and product offerings. This bridges the gaps between query/requirement (suppliers) and target solutions (vendors) and open possibilities for worldwide collaborations and cooperation within engineering. The study by CHIEH-YUAN TSAI, indicates that they generally followed method of Boolean search is less accurate and effective when compared to the proposed structural search and product retrieval method. The above-mentioned research suggests measurements of structural similarity between the query and each product description in the system database. This will lead to a more refined product retrieval. Since such a virtual enterprise has heterogeneous environment with numerous partners, XML being a neutral and flexible data exchange language is a great solution. The author thus suggests XML DOM (Document Object Model) technique to implement an algorithm that calculates similarity between a query XML document (QXML) developed from the query received and a database XML documents (DXMLs) which store the structural product details uploaded in the virtual enterprise server by the partners. (CHIEH-YUAN TSAI, 2004) [7] Figure 3 indicates a framework of the proposed system,

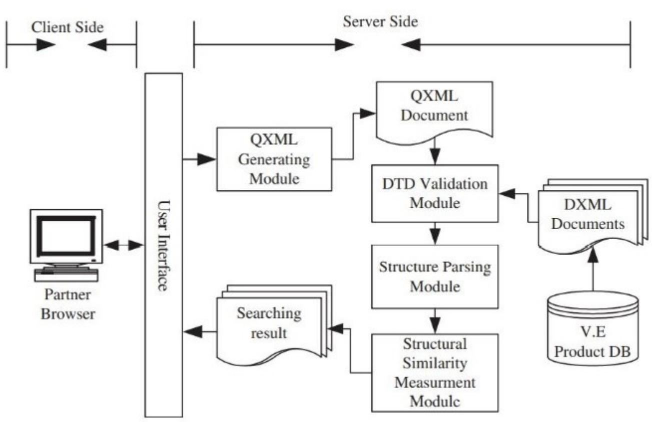

Fig. 3. Framework for virtual enterprise case [7]

Further developments to such resource management platforms by achieving intelligent integration between heterogeneous systems has been described in study by Chinta Someswara Rao. This paper suggests a PDM-string matching approach for XML. This can be achieved by designing ontology for a set of databases in a STEP (Standard for Exchange of Product Model) file for PDM (Product Data Management) system of engineering enterprises. The paper experiments this approach by construction of ontologies to extract data from STEP files of different assemblies. (Chinta Someswara Rao, 2016) [8].

C. For Product Lifecycle management in manufacturing industries

A complete understanding of PPR (product, process and resource) can be achieved by manufacturing industries today with the help of a PLM software. This helps leverage understanding of the entire product portfolio including design, resources, technology and processes to make engineering decisions. However, companies face challenges to integrate data, files and information from different monitoring software such as CAD, CAE, PDM and so on for PLM.

PLM XML is one format that is emerging to facilitate this interoperability using XML. It is developed by Siemens PLM Software, one of the world's largest PLM software and service providers. PLM XML is a standards-based format for product lifecycle management data that enables more efficient, secure and scalable data exchange. It can be used to exchange data between enterprise systems such as ERP, supply chain management systems, and manufacturing execution systems, services and applications such as 3D modelling and PLM.

A research article in the International Journal of Computer Integrated Manufacturing by Sang Su Choi suggests a neutral extendable file 'PPRX' abbreviated from 'PPR eXchange' based on XML to support the management of PPR information based on the structure of the PLM Services. The proposed system is implemented on a workstation in a general assembly shop of an automotive company. The PPR accumulates data of 70 products, 90 processes and 113 resources. Figure 4 shows a flowchart to explain integration of this data.

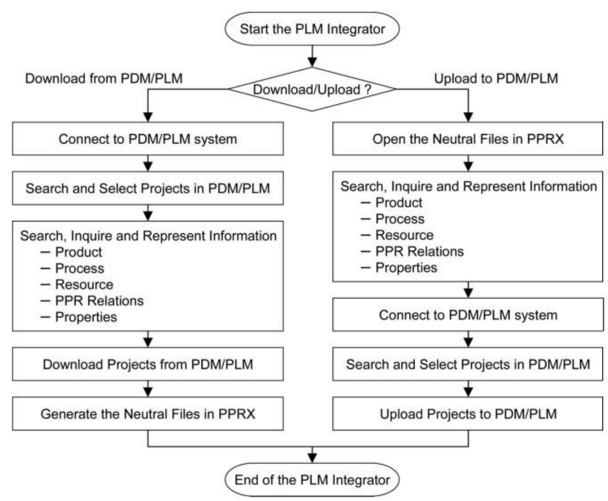

Fig. 4. Functions and basic flowchart of the PLM integrator [9]

The study proves that the time required to collect and arrange PPR information of this assembly show is optimised from 32 hours to 2 hours with the help of PPRX and PLM integrator. (Sang Su Choi, 2009) [9].

D. Planning, Simulation and Development of process plant and engineering systems

As per the VDI guideline 3633 Part 1 – simulation of systems in materials handling, logistics and production – structures a simulation study in different steps and phases. Fig. 5 shows the workflow of a simulation study with the iteration loop caused by changes during the plant development process. As we can see, the feedback loop from analysing results returns to the data collection process adding iterations making it a time-consuming process. Also, the data we collect for planning processes for plants and other engineering systems

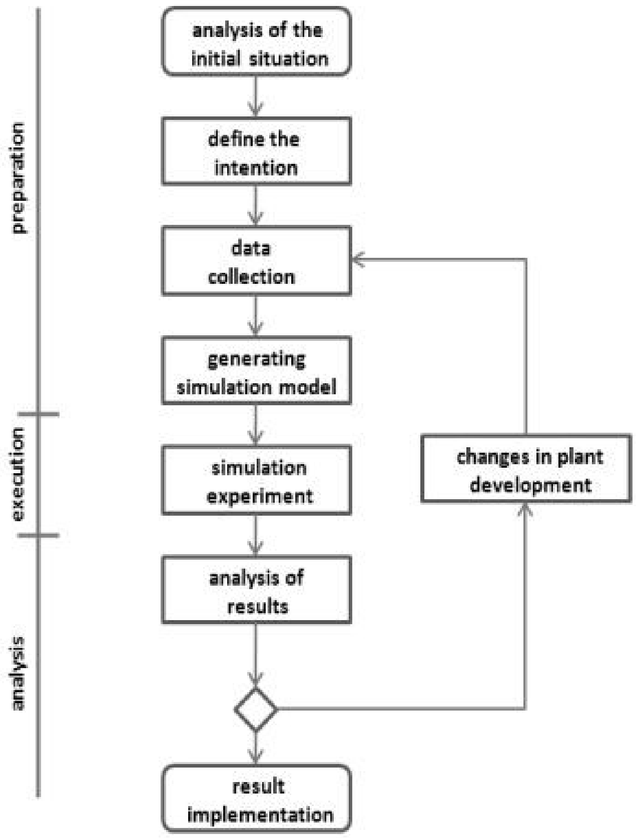

Fig. 5. Flowchart for Plant development process [10]

is characterized by interactions and information exchanges between different engineering disciplines. Since consistent and up to date data collection is an integral step in Production process planning, all the information and simulation results need to be stored in an easy and exchangeable format. In a process plant, the piping and instrumentation diagram (PID) is the central document for the planning. It represents a symbolic illustration of the plant devices, the equipment of measurement and control technology and the connection between them. It is used throughout the lifecycle of a plant. The continuous iterations to be made in a CAE (Computer aided engineering) supported simulation model can be facilitated by seamless extraction of data from PID. For this a flexible exchange format as published in International Electronical Commission in 2005 as part of PAS 62424 known as ”CAEX” (Computer Aided Engineering eXchange) is ideal. Easy access to complete information of parameters such as material and energy flow connections in a plant hierarchy will thus facilitate the generation of an automated simulation model. (Mike Barth, 2009) [10].

VI. CONCLUSION

We discussed about XML and how it can help engineering organizations. The capacity to address difficulties such as these distinguishes excellent engineering organizations from average ones, and it can be the difference between effective product development and failing to cultivate the potential market for its products. Engineering firms that utilize the full power of XML for calculation management have a distinct advantage in terms of product development timeliness, product quality, ease of interface with enterprise applications, regulatory compliance, and superior commercial performance.

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Study on JSON, its Uses and Applications in Engineering Organizations

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Abstract — **In today's world, data sharing between multiple devices and applications is a necessity. The storage of data is preferred over cloud than on the device. Web services are being used to communicate with the cloud and exchange data for the purpose of communication. For ensuring a consistent interaction between various platforms and devices, data must be represented using a common data format, such as JSON or XML. JSON is one of the most common data exchange formats on the internet, however there is hardly any consensus on a theoretical foundation for dealing with JSON. As a result, in this paper, we discuss the existing data exchange formats used in engineering firms for transferring information and focus extensively on JSON, what is JSON, how it differs from other markup languages and its uses. In addition to it, there is an extensive research and practice going on towards implementing Industry 4.0 applications in most engineering industries. Hence, we additionally look up on what are Internet of things & Industrial IoT. And finally, the application of JSON in production, manufacturing and other engineering industries, its benefits, drawbacks, future scope, and current research being carried out on implementing cyber physical systems in mechanical industries.**

Keywords — Data Exchange, JSON, XML, Mechanical Industries, Industry 4.0, Internet of Things, Industrial Internet of Things, Production and Manufacturing.

I. Introduction

In the past, data sharing between applications was done through file transfers. In today's era, network capacity and reliability have increased to the level where message-based communication between applications has become new standard. Cloud infrastructures and commoditized Web provide more options for data interchange design, each tailored to the needs of the business context's interactions. The shift away from nightly batch transfers to synchronous, real-time web service interactions demands retooling of development organizations and preference for vendors who support these methodologies.

According to Facebook statistics, there are 2.85 billion monthly active users, with an annual growth rate of 11%. Aside from that, active profiles upload 136,000 photos per minute, make 510,000 comments, and publish 293,000 status updates. Wikipedia pages, on the other hand, create at a rate of 2 modifications per second, according to Wikipedia analyst statistics. Wikipedia currently contains 5,726,316 English articles and adds 553 new ones every twenty-four hours or so. The storage, collecting and managing this vast amount of data is a big challenge for these prestigious organizations. Every company has its own way of dealing with enormous amounts of data; for example, Google has 14 distinct Data Centers throughout the world for the purpose of handling huge amounts of data. [1]

For the purpose of handling massive amounts of data, Facebook developed its own way known as the Presto mechanism. There are a variety of organized, unstructured, and heterogeneous data file formats available, such as CSV, Image file format, Plain text, Binary file, XML, JSON, HTML, Excel, PDF, and others, from which we can extract data based on the requirements. Data management and utilization are more important than ever before in today's data-driven world, as only those organizations that recognized the enormous influence of data analysis early on are dominant and ruling the industry. [1]

There are numerous examples that emphasize this point, such as Netflix's replacement of Blockbuster (an American-based organization that provides home theater, video games, DVD, streaming, and on-demand videos), Amazon's continued disruption of offline retail markets, and Uber's constant dilution of the taxi industry. Many tools, such as EXCEL for beginners and SAS (Base SAS and Enterprise Minor), IBM (Cognos and SPSS), ANGOSS, R, Weka, Pentaho, JMP, Rapid-I, Python, etc. for experts, can be used to explore, prepare, scrubbing, and visualizing data. They can also be used to perform complex algorithms like Machine learning, Natural Language Pro (NLP), Deep learning, Neural network, Artificial Intelligence.[1]

II. Different programming languages used for data exchange

Modern information systems are made up of a variety of applications and subsystems that must operate together to meet an organization's information demands. It was extremely difficult for applications that were developed independently to interact together. Fortunately, all recently developed applications and subsystems use objects. [2]. Unfortunately, the form of the object varies. It is always preferred to have a common platform as the standard for data exchange rather than mapping an object to all other potential forms.

XML is an acronym for "Extensible Markup Language." A set of symbols that can be read by humans and computers is defined as a markup language. These symbols can be used to arrange and name different areas of a document's text. Since XML provides freedom to software developers to create self-explainable syntax or languages, it is extensible. This language does not always convey data, but it does allow developers to store and arrange information in order to choose how the data will be displayed. It is a markup language which was established with the purpose of storing data and information. XML is used as the standard format in several organizations [2]. There are various reasons behind XML's appeal as a data interchange format on the Internet. To begin with, XML has similarities with the the existing Standard Generalized Markup Language (SGML) and Hypertext Markup Language (HTML). A parser created to handle these two languages can easily be expanded to support XML. For instance, XHTML has been defined as a formal XML format that is successfully understood by most HTML parsers. [3]

YAML is another language that was created with humans in mind (and as such easily editable with any standard text editor). Its notion is typically comparable to that of re-structured text or Wiki syntax [3], both of which aim to be readable by computers and humans. YAML 1.2 delivers a JSON-compatible platform. Thus, a valid JSON script is also a valid YAML; but the reverse is false.

REBOL is a human-readable programming language which is easily editable. It accomplishes this by employing a basic free-form syntax. It hardly has any punctuation and it has a diverse variety of datatypes. URLs, date, emails and time values, tuples, strings, tags, and other REBOL datatypes adhere to industry standards. Because REBOL is developed in a metacircular form, it does not require any additional meta-language. JSON was inspired by the REBOL programming language.

III. Introduction to JSON

JSON (JavaScript Object Notation) is a lightweight data-interchange format. It is easily readable and writable for humans and robots that is generated and parsed by computers. It is a text-based script that is not dependent on the language however it works on the syntax of the C language family [4]

JSON has conquered the globe. In today's world, when the two applications are communicating, its most likely being done by JSON. All of the major players have embraced it: The most popular web APIs includes Google, Facebook, and Twitter. The first JSON message was delivered in 2001, and since then, the data format has grown in popularity as a means of storing and transporting data. In fact, JSON works in a similar way to XML because it accepts data from a web server and sends it to a web page. However, it requires less programming and is compact, allowing for faster operations and data transmission.

The primary data format in JavaScript applications is JSON. As JavaScript gained popularity, more JSON messages were created. Other formats are also compatible with this programming environment, but they require more effort, whereas JSON is fully built-in and properly coupled with JavaScript. JSON is also language-independent (like XML), thus it can be used with any computer language despite being built in JavaScript.

JSON is a key-value pair and ordered list-based text-based representation of structured data. JSON scripts are libraries made up of key–value pairs. The value can be defined as another JSON document, thus allowing for layering of infinite level. Figure 1 explains an example of a JSON document. JSON also supports arrays and atomic kinds like numbers and texts. Arrays and dictionaries can hold arbitrary JSON documents, completing the format's compositional capabilities. JSON has gradually gained popularity and in today's world, it is one of the most common formats for transmitting data on the internet.

```
{
  "name": {
     "first": "John",
     "last": "Doe"
     },
  "age": 32,
  "hobbies": ["fishing","yoga"]
}
```

Figure 1 : A JSON document [5]

The JSON structure constitutes of below mentioned concepts: [6]

A. *Object:* "An object can be defined as an ordered set of key-value pairs. A key-value pair is enclosed by open and closed braces '{' and '}' respectively. The separation in each key-value pair is done by a comma ','. A key is a string content followed by ':' colon. The example in Figure 2 is constituting of two key-value pairs which is basically the object Java Script with scope type."

B. *Array:* "Array can be defined as a collection of values which is ordered unlike object. It is enclosed by open and close brackets '[' and ']'. The values in an array are separated by comma ','. In figure 2 array multi values and array of number can be observed."

C. *Value:* "A JSON value can be a primitive type value (string, numeric, Boolean), a structured type (object, array) or null. Json document can be defined as a nested structure by using objects and arrays as values." The values of the object and arrays are mentioned in Figure 2.

```
{
    "_id": ObjectId("50319491fe4dce143835c552"),
    "binaryType": BinData(2, "dGVzdGFuZG8="),
    "dateAsISO": Date("2014-01-31T22:26:33.000Z"),
    "timestampType": Timestamp(1421006159, 4),
    "dbRefType": DBRef("some_collection",
            "50319491fe4dce143835c552"),
    "undefinedType":undefined,
    "longType": NumberLong("9223372036854775807"),
    "booleanType": false,
    "nullType": null,
    "regexType": /\/^S\//m,
    "stringType": "some_value",
    "objectType": { "property": "some_value" },
    "arrayMultiValues": [ 48, "50",
        {"property": "teste"},  [1,"some_value"],
        true, BinData(2, "dGVzdGFuZG8=")   ],
    "arrayOfNumber": [ 1, 2 ],
    "javascriptType": { "$code":
        "var a = function(param){console.log(param);};"},
    "javascriptWithScopeType": {
        "$code": "int x = y", "$scope": { "y": 1 } },
    "maxKeyType": { "$maxKey": 1 },
    "minKeyType": { "$minKey": 4 },
}
```

Figure 2 : An Extended JSON document [4]

JSON is an original format of JavaScript. This indicates that it does not require any particular API or toolkit to parse JSON-formatted data. This has a number of benefits, including ease of parsing and generation, low transmission costs, and good cross domain compatibility. In a nutshell, JSON is a data-sharing format that makes it pretty simple for exchanging server-side data structures into JavaScript object data formats. These features result in making JSON an ideal platform for data interchange.

The filename extension for JSON is '.json'. The Internet Media type is application /json and the Uniform Type Identifier is public.json.

IV. WHY IS JSON PREFERRED OVER OTHER MARK-UP LANGUAGES?

Mobile applications have grown in popularity recently, and they frequently require access to a database maintained on a server. Web APIs allows access to these data; as a result, these web APIs must have a fast response time to ensure that the relevant data is displayed to the end user without delay.

For data to be usable by apps, it must be formatted according to a standard that can be interpreted, read, and used by both the API and the application that will access it. JSON and XML are two of the most used formatting formats for online API services. Both JSON and XML formats have advantages and disadvantages that qualify them for specific applications, and either can be employed depending on the system's requirements. JSON has a simple structure making it accessible for simple information exchange, making it one of the widely acceptable data formats.

One of the most major advantages of JSON is that it has a smaller file size, making data transmission faster. As JSON is compact and simple to comprehend, the files appear cleaner and better structured without empty tags and data. JSON is easier for people to use and read because of its simple structure and minimal syntax. Other markup languages, on the other hand, is frequently criticized for its complexity and outdated standard, owing to the tag structure, which makes files larger and more difficult to understand.

JSON differs from other markup languages in the manner data is stored. When compared to other markup language, which stores data in a tree structure, JSON stores data as a map, which includes key-value pairs. Furthermore, JSON does not require end tags and may work with arrays (data structures with groups of elements).

JSON has evolved over the years to become one of the leading markup languages[7]. According to Stack Overflow, JSON, at present, is the more popular subject of discussion than any other data transfer standard.

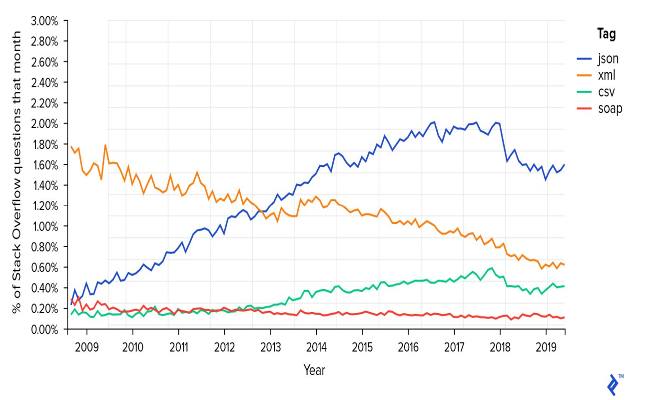

Figure 3 : Stack Overflow Trends (Stack Overflow, 2009-2019) [7]

JSON is the most searched markup language as per Google Trends. [8] The same trend can be observed in the Fig 4.

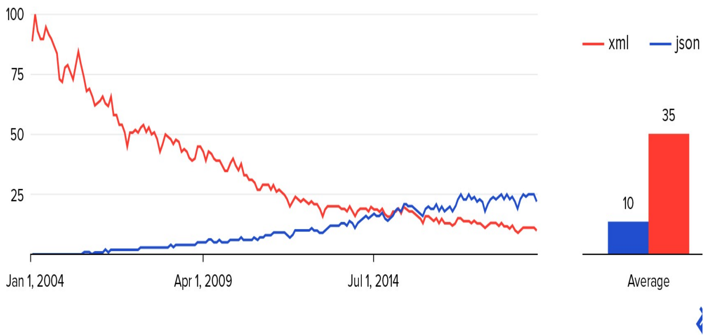

Figure 4 : Google Trends (Google, 2004-2019) [8]

V. USES AND MERITS OF JSON

According to our study, we found that JSON produces a number of uses and advantages. They are listed as given below:

A. *Uses:*

i. JSON is utilized for developing JavaScript-based applications which incorporate browser add-ons and webpages.
ii. The JSON format is also utilized for sorting and sending structured data over a wide range of network.
iii. The primary purpose of JSON is to send data between a server and web API.
iv. It can be easily applied to any contemporary programming languages. [6]

B. *Merits:*

i. JSON is a native format of JavaScript implying that there is no requirement of any special API or toolkit that can parse JSON-formatted data.
ii. It is easily readable and writeable.
iii. It is a lightweight data exchange format which is based on text.
iv. It is not language-dependent.
v. JSON encoding is terse, which requires less bytes for transit. [6]

VI. INDUSTRY 4.0, INTERNET OF THINGS AND INDUSTRIAL INTERNET OF THINGS

In recent times, there is a tremendous growth in the number of sensors and edge-based technologies in our lives. If we look around us, we rely on a large number of sensors-equipped devices and applications, such as smartphones, smartwatches, smart toothbrush and or video games. There is an increase in the number of applications that are using these sensors and are producing data. Some of the examples include self-driving cars on roads as Google Maps which are available by Uber and Google. Smart habits and healthcare are becoming more prevalent in our lives, Hapifork, an electronic fork that can track eating habits. Oral-B, one of the famous toothbrush brands produces a smart toothbrush that controls dental hygiene. The Apple health kit has the capability to track fitness, nutrition, and sleep cycle, etc. We can also find smart houses with temperature and lighting controls. This leads us to modernize our cities and introduce us to the concept of smart cities. These objects which are contributing in making our daily lives easier directly relate to the Internet of Things (IoT) and Industry 4.0. [9]

Industry 4.0 is a new idea that addresses the advancement and development of current production systems by bringing together new industrial automation and data framework technologies [10]. The Internet of Things (IoT) encompasses a wide range of technologies and methods for interacting tangible and non-tangible items or substances via the Internet.

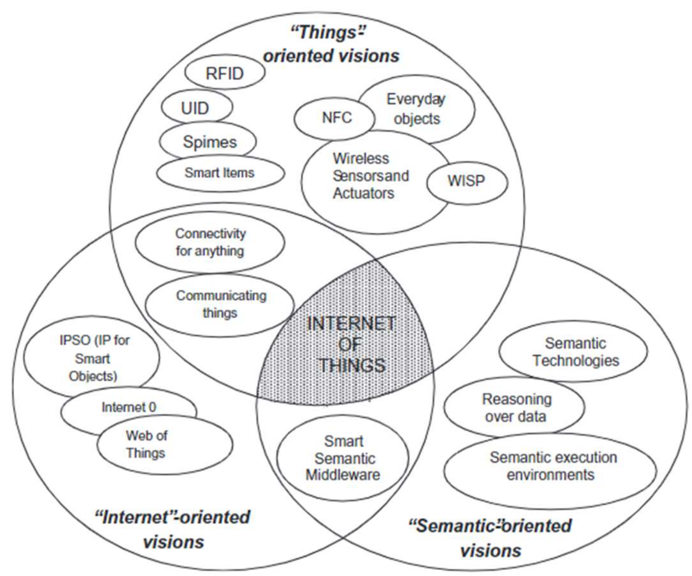

Figure 5 : Main visions of the Internet of Things [9]

Machine to machine communication has existed since the initial commercial use of telephone lines in the 1970s, and also when wireless was introduced in 1990, because all of these know-hows are based on industry-specific or restricted networks for a closed purpose. Machine-to-machine (M2M) applications can now be employed widely thanks to growing wireless technologies.[9]

The evolution of IoT can be represented as follows:

1. RFID (Radio-frequency identification) and sensors,
2. Web services and interconnections, and

3. Social Internet of things (SIoT), Cloud of things (CoT) and Information-Centric Networking (ICN) as illustrated in Figure 6. [9]

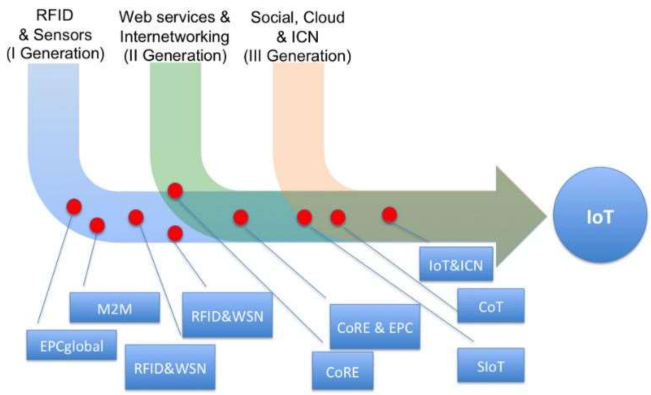

Figure 6 : Evolution of the Internet of Things [9]

The rise of the Internet of Things is having a significant impact on the world of smart devices and sensors. We can clearly predict that by 2025, this will have a massive financial impact on the economy, amounting to trillions [11]. IoT will have significant influence in every aspect of lifestyle and business.

The Industrial Internet of Things (IIoT) refers to a network of sensors which are connected together, devices, and instruments that are connected to organizational applications on computers, such as production and energy management. This connectivity allows for data collection, interchange, and analysis, which could lead to enhanced production and efficiency, as well as other economic benefits. The IIoT is a development of a distributed control system (DCS) that employs cloudification to improve and stabilize processes, allowing for greater automation [12]. It allows equipment and systems to interact among each other, as well as facilitating decision makers with relevant information for managing and enhancing production operations. [10]

Technologies including cybersecurity, cloud computing, edge computing, mobile technologies, machine-to-machine, 3D printing, advanced robotics, big data, internet of things, RFID technology, and cognitive computing influence and enhance the IIoT. [12]

VII. JSON in the Production and Manufacturing Industries

Industry 4.0 is a one-of-a-kind industrial transformation since it can rely on pre-existing infrastructures simply by linking technology.

Enterprises are developing unified equipment control centers and introducing unique techniques of production process control, according to the current trend in modern production system development. As a result, we can assume that the lines between various physical components such as computational devices and industrial robotics, as well as the virtual model, are becoming increasingly blurred, leading to the creation of the CPPS acronym (Cyber-Physical Production System). [13]

In this respect, the data generated by equipment on assembly or production lines adds to a fascinating case study. xFactory assembly lines presently generate massive volumes of data, which are stored and reused. Industries should ensure enhanced interoperability among their facilities and solutions as technology advances. To do so, a growing and more common technique is to utilize semantics, or to be more specific, ontologies, to add more value to the event of data, allowing it to be interpreted by machines or equipment and perceived in the similar way across various data centers. [14]

For the past 20 years, most data management systems have relied on relational data as their bread and butter. JSON, which uses a key-value pair paradigm, has become a new state of art which is used for interchanging and transmission of data across various systems. As a result, data gathered from assembly lines is often saved in SQL databases, XML files, Excel sheets, or JSON streams as tables, key-value pairs, or trees. Some of these formats, such as SQL, are difficult to convert into graph data due to their structure, but JSON is quite simple [14]. The Figure 7 shows an example of how the data is obtained and parsed in an assembly line with an aiding tool.

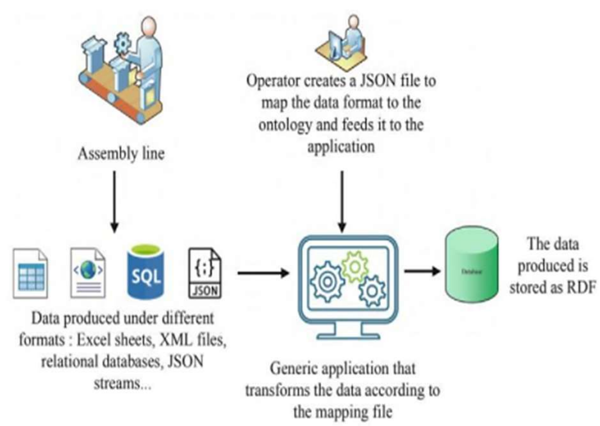

Figure 7 : Use of JSON in the assembly line [14]

JSON was also employed for data transfer on a distributed network for a CNC system, according to studies. By developing an open program interface for the interaction between the components of a distributed CNC system, the control system's distributed design enabled the integration of automated and robotic equipment into the cyber-physical production system (CPPS). A unified protocol that integrates the excellent performance of TCP sockets with the capability of many-to-many routing between endpoints is required for more effective interaction. The research was concluded by stating that there are many advantages, out of which one being that JSON used up very less space; 1 KB – 100 KB provided best performance results. Hence, stating that JSON is the best tool for data transfer in a distributed CNC network.

The idea of commissioning distributed CNC system components on a personal computer (PC) or a general-purpose server was recommended while examining the communication between operating system processes. It is possible to think about inter-process communication (IPC) for POSIX-compliant operating systems. This is the most recurrent framework for executing complex CNC logic. The G-code control program-parsing module, for example, communicates with path optimization and thereby advances the planning module. Both of these modules are evident in that they do not complete tasks in real time, and they can typically be loaded on standard PCs. [13]

Another research has been carried out in the field of logistics management. It focused mainly on the document management system with the help of various data exchange-based applications such as WebSocket++, Boost Asio, JSON, etc. and combining them for an optimized output. The optimum solutions for an electronic document management system for a transport-logistical cluster were found to be monthly complete copying, weekly differential copying, and daily incremental copying. Only the first level of the transport-logistical cluster would be served by backup systems. Aside from the need for speedy data recovery, archives and backup copies would be maintained in remote data centers for security reasons. There is also a need to keep information in an unmodified state for lengthy duration. For such scenarios, document archiving, e-mailing, accounting, and other functions would be necessary for completing legal obligations, investigating occurrences, and preparing reports. [15]

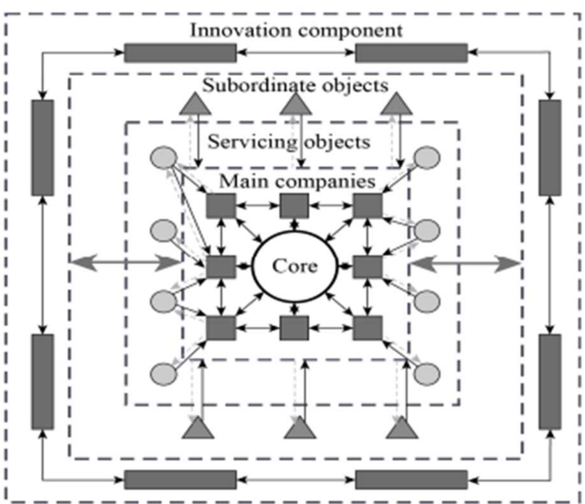

Figure 8 : Typical structure and information flow of transport-logistical cluster [15]

VIII. JSON IN OTHER INDUSTRIES

Despite having various applications in several industries, JSON is being used for data exchange in numerous sectors. Apart from its usage in the field of production and manufacturing, JSON has been spotted as the means of data exchange in some agriculture applications. JSON is being utilized in Henan Province, China, to exchange data amongst multiple agricultural applications, which has aided in the development of an integrated service platform for information in rural regions. [16]

With the deployment of 5G technology, JSON has found the route in the field of vehicular communications for tackling heterogeneity problems. For the better adaptation of cloud computing, data in the form of XML is converted to JSON format by a middleware for ensuring the smooth extraction of information and optimization of results.

In an IoT solution called Crowdsensing, which is a technique of gathering collectively shared data from large group of individuals for the safety of citizens and public service, JSON plays a vital role in for data exchanging from the mobile applications to the concerned authorities. [17]

Thus, applications of JSON can be found in most IoT applications, smart factories, communication technologies, mobile applications, and cloud platforms. [18]

IX. ADVANTAGES AND LIMITATIONS

Every technological development in this ever-changing world of advancements will have its own advantages and limitations. In the same way, JSON too has some limitations over its numerous advantages. [19]

Advantages:

i. *Efficient and Fast*: JSON has a basic syntax that is also self-explanatory. JSON can be interpreted by apps that have no idea what kind of data to anticipate. JSON is also portable and lightweight. With less characters, you may achieve the same results as XML. This has the obvious benefit of allowing for quicker execution. This boosts operational efficiency. [19]

ii. *Responsive:* JSON is a simple data format to parse. Parsing does not necessitate any additional code. JSON server-side parsing has the advantage of improving responsiveness. Clients will receive speedier replies to their inquiries as a result of this. JSON is extensively used as a standard data communication format as a result of this. Aside from that, if you're dealing with an object-oriented system, JSON is a good choice because it's simple to map. [20]

iii. *Key Pair Approach*: JSON is a simple data format because of its key/value method. The JSON object is provided in curly brackets, and the key/value pairs are within the space. A colon (:) and commas (,) separate them. It also improves the efficiency of write and read operations. [19]

iv. *Data Sharing:* The exchange of data is one of JSON's most prominent functionalities. It's used to connect front-end and back-end languages so that data may be shared. Serialization is the process of converting the front-end language to JSON text. Deserialization is the process of converting JSON text to programming data. The serialization and deserialization operations of JSON are rapid, making it easier to transfer structured data. [19]

v. *Schema Support:* It supports a broad range of browsers and operating systems, therefore apps created using JSON coding don't take much work to make them all browser compatible. During development, the developer considers several browsers, although JSON already has such feature. [20]

Limitations:

i. *Verbose:* Given how simple and small JSON code is, the presence of verbosity on this list may come as a surprise. JSON, without a doubt, utilizes less characters than its competitors. When working on special-purpose projects, however, the same characteristic becomes a disadvantage. The reason for this is that JSON code is not concise, which negates the point of utilizing it in the first place. In these circumstances, you might want to check into different data formats to see if they can provide you with the efficiency and results you want. [20]

ii. *Missing Comments:* The comments are crucial for comprehending the code. In JSON, you may utilize comments, however there are certain restrictions. That implies you will have a difficult time defining the data inside the data. In addition, certain JSON libraries do not accept comments as inputs. You will have to utilize the pre-processor to get rid of the comments in these circumstances. This, however, needs an extra tweaking in order to parse the file. [20]

iii. *Less Secure:* Because a JSON service sends a JSON response wrapped in a function call, which is executed by the browser, JSON may be highly hazardous when used with untrusted services or untrusted browsers. It can be hacked if it is used with an untrusted browser, making the hosting Web Application vulnerable to a range of assaults. [20]

iv. *Date Data Type:* The date data type is ignored by JSON. Due to the lack of a date data type in JSON, developers must find an alternative. Furthermore, converting JSON data to another format is time-consuming. [20]

X. CURRENT RESEARCH ON JSON

To read and write to a database, online applications are increasingly relying on web services. There are several tools for building and documenting web services, such as Swagger, but no technology for temporal web services. A temporal web service is one that gives a temporal perspective of data, which includes not just present data but also historical data or how data has evolved over time. [21]

Recent research has modelled temporal JSON as a virtual document in which time metadata is merged with JSON data to capture a JSON document's dynamic history and to make temporal searches easier. When the JSON data is alive, the time information is recorded. [18]

New technologies offer a huge possibility for vast expansion of information access for everyone at any moment in their lives. The gradual spread of mobile learning has altered the way people study. Mobile learning has become increasingly significant in learning and teaching in higher education as the reputation of utilizing mobile devices has increased. Many m-learning services are provided via LMS. Semantic Web Technologies, on the other hand, provide standards such as RDF, which allow characterizing Web resources with their metadata. This requirement has prompted the e-Learning community to look for new ways to improve the interoperability of online learning systems.

To address the problem of e-learning material heterogeneity, research has been conducted to produce a semantic web solution targeted at translating JSON format declarations into RDF format utilizing the JSON-LD mapping mechanism on the LRS System. [22]

The Internet of Things (IoT) is a popular application and technology these days, which means that a great amount of data will need to be shared among devices and application domains. If data interoperability is a requirement for your implementation, you must use the Semantic Web as a strategy that leads to a combined approach known as the Semantic Web of Things, as most web community recommendations suggest (SWoT). [9]

WoTJD for WoT utilizing JavaScript Object Notation Linked Data was recently demonstrated in research (JSON-LD). WoTJD assists IoT users in overcoming the key obstacles of data interoperability in WoT by assisting in

1. Designing and integrating WoT applications,
2. IoT data parsing and annotation, and
3. Linking domains utilizing domain knowledge expertise. [9]

XI. FUTURE SCOPE

JSON is clearly a force to be reckoned with. JSON has become the most used data transfer format, thanks to JavaScript's popularity as the most extensively used programming platform today. JSON is an excellent choice for simple, tiny projects. However, as we strive to build bigger and better apps in the future, the overall complexity of our software will inevitably rise. Several organizations have attempted to create equivalent standards for JSON, using the tremendous features of XML as an example. [23]

Once programmers have switched to JSON for program-to-program data serialization, they seldom go back to XML. However, as more programmers begin to use JSON, the need for new capabilities such as the ability to specify a schema for a JSON object will certainly get louder. The "JSON Media Type for Describing the Structure and Meaning of JSON Documents" is an early example of this tendency to provide value. According to Crockford, the ability to add value to JSON without changing it is a critical feature. [24]

JSON is transitioning from being a well-kept secret known only to a selected few to becoming the obvious solution for mainstream data applications. The most intriguing component is undoubtedly the value-add capabilities that will become part of the developer's toolkit as JSON gradually takes over the hard lifting of data encoding and exchange [23].

XII. References

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