Article

Cloud-Hosted Advanced Manufacturing and Assembly

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Abstract

The demand for advancements in manufacturing technology is pulled by both competitive pressures and just in time ambitions of customers. Competitive forces mandate that the costs of raw materials, resources and infrastructural requirements are all asymptoted to bare minimum. How this world continually evolving as a global village can lower each of these costs is the challenge. A solution is being sought in making man, material, and machines facilitated from cloud.

The cloud thinking prescribes that the resources are available to all the prospective or current users at call where one pays for actual use. The overheads are thereby minimized. This work attempts to review the applicability of this resource and thinking, i.e., of cloud as a facilitator of just in time, mass customization to maximize value @ design to manufacture to assembly of engineered products. The paradigm is based upon utilization of innovation and cloud to add value. It attempts to qualify that Innovaluation (innovation and valuation) is the mantra for tomorrow's competiveness or rather competence.

Keywords: Cloud, Cloud computing, Cloud storage, Cloud assembly, Manufacturing over the cloud, Cloud-based design and manufacturing

Manufacturing Technology's Advance Provisions

The manufacturing world, to move faster, is all set to be fueled by inter-connected capabilities, viz., advanced manufacturing technologies, Industrial Internet of things (IIoT), cloud as technology, and so on [1]. The principal author's earlier work published in a four-part series in previous issues of this journal [2–5] attempted to count the role of erstwhile up-gradations in technology that have been more than continual by way of synergistic integrations, and target the fourth stage of revolution in technology. The review of developments and analyses thereof identify that success is essentially driven by integration of hard and soft aspects, wherein the technology and (IIoT) constitute the hard side of manufacturing while the practice part tends to construe deployment of *cloud* from both the hard and soft sides. The use of devices (like erstwhile pagers as hardware), the inventiveness, and/or the zeal to serve customers providing high-class service (as software) is not new and presumably been invented in previous century. One example was sketched as in case of a street hawker using pagers in an earlier work [6]. The Part-I of the aforesaid series had also stipulated the presence of wetware [2], a hybrid of software and hardware, to which this cloud-ware technology seems to conform.

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However, not reviewing the software side in this article, we consider cloud with its flexibility to motivate manufacturing for making it competitive and advanced. Thus, in this work we attempt to especially explore the latter, that is, make a case for use of cloud as a resource for manufacturing, and review the developments in cloud manufacturing.

Exhibit 1.Basics of Cloud Technology

Cloud is a network that promotes availability of requested virtual resources (over the Internet) providing as a It has rapidly become predominant due to a number of technical reasons, including: improvement of energy efficiency, optimization of hardware and software resources utilization, elasticity, performance isolation, flexibility, and on-demand service schema [8], and several economical benefits including minimal capital and operational expenditures (CapEx and OpEx). Cloud serves as a pool of shared resources that can be managed as a single logical entity that can be provisioned and de-provisioned on demand, and without needing to understand the underlying technology [9]. One only pays for the bandwidth and server resources that are needed. After completion of work, the whole thing is just turned off!

National Institute of Standards and Technology (NIST) [10] defines cloud computing as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider's interaction. Aceto et al. [11] claim accurate and fine-grained monitoring of cloud computing activities are required to efficiently operate these platforms and to manage their increasing complexity. A platform is a collection of/or a group of integrated and networked hardware, software and Internet infrastructure. Cloud computing uses the power of the Internet and grid computing to move towards a virtual enterprise that is not limited by hardware constraints. Thus, they act as enablers for business transformation.

On the operational side, cloud model delivers services [12], duly composed of five essential characteristics, three service models, and four deployment models.

- With cloud computing, you have access to a pool of virtualized resources that can expand and contract on demand, while in the traditional model peak loads are provisioned at maximum utilization time. In cloud computing only actual usage charges are levied. One does not have to pay for the resource when not in use. It is because the unit cost of on-demand capacity may be higher than the unit cost per time unit of fixed capacity [13]. The resources are provisioned at a fast rate. Instead of taking weeks to set up the environment, it can be provisioned in minutes.
- To further reduce costs, provisioning of infrastructure and application services can be outsourced to cloud providers. Thus hardware and software can be rented on a pay-per-use basis.

Looking at such advantages, the manufacturing of tomorrow must be benefited [14]. Conversely, the clouds are expected to be helpful as they expect to change industries in the following ways:

- The use of clouds changes how resources are procured, sourced, and delivered.
- Applications need to be built, need to be machine independent, container-managed, with small memory.
- Collaboration using the cloud is not restricted to a single geographical location.

Albeit, the integration of cloud computing with manufacturing, the former "continue[s] to grow in terms of both hardware resources and traffic volume, thus making cloud operation and management more and more complex [7]." It hence necessitates an exhaustive exploration of cloud and its use in manufacturing, towards which we first qualify the cloud, its definition and its characteristics as in Exhibit 1. But first let us explore the strategic need for the deployment of advanced technology itself for manufacturing and assembly. Hence we shall attempt to investigate the changing paradigms in the use of technology, and how traditional manufacturing gets influenced, and concurrently attempt to understand the still bigger question: why?

A cloud, since ages, has been perceived as a giver. Considered as an object of 'hope', clouds are associated with the sustenance of quality of life. How are givers equipped to contribute to evolutionary stimulus is explained in a recent work [15]. Today, because of resource constraints, competition, and the unending desire to cut costs with unprecedented zeal, the virtual cloud of resources is physically being positioned on the

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ground to give benefits [8], like just the one which gave us hope from the sky. If the characteristics in Exhibit 1 are realized, cloud sure serves at the summit of the triad with technology, integrated with Internet of Things (IoT), and the promises to further realize unprecedented manufacturing efficiencies. Evidently, at the face of such promises, today the industry is wondering as to how any company may benefit from cloud-assisted software solutions [14].

Given that technology is innovatively harnessed to the benefit of both suppliers and customers [6], the progressive manufacturers are likely able to support customers while they are innovating [16]. Thus cloud computing is slated to facilitate various supply chain processes, including resourcing, outsourcing, deployment and production, wherein dedicated initiatives are taken to pair machines with mobile devices. Thus strategically, the cloud technology can be deployed to help executives and warehouse managers access the information they need to properly run and manage the warehouse. Following are interim benefits of constituting technology:

1. Benefits of Internet – The Internet is a catalyst for much of our innovation and prosperity in terms of saving of time and money, so as to change the way we work and live. Quips the European Commission: "Hundreds of seemingly unrelated changes are coming together now – in space and time, enabling leapfrog in what the Internet can do for society and economy in the future" [17]. Giving us new opportunities for growth, innovation and knowledge improvement, the Future Internet Assembly (Exhibit 2) promises more expedient opportunities.
2. Cloud-based automation solutions – The manufacturers can increase efficiency and performance only by integrating and collaborating with suppliers, as joint solutions can help manufacturers succeed in presence of external and internal forces, namely, economic, social, or performance/ operational based.

As a contributor the Future Internet Public Private Partnership Program of the European Commission is attempting to make key societal infrastructures and business processes more intelligent and sustainable through tighter integration with the Internet [18].

Exhibit 2.Future Internet Program

The 300-million-euro public-private partnership program on the future Internet launched by European Commission is focused on short- to middle-term research. The core of this program based on integration of already existing research results is a platform that implements and integrates new generic but fundamental capabilities of the future Internet, such as interactions with the real world through sensor/actuator networks, network virtualization and cloud computing. This includes a smarter content creation system for professional/non-professional users. [18]

In view of this hope cast as above through deployment of cloud, manufacturers have only two options to achieve their goal in this competitive market. These are (i) either they have to buy more servers and resources or (ii) simply move to the cloud. – a network that delivers requested virtual resources as a service. To map its varied potential, we review Aceto et al. [11] who brainstorm the various issues, basic concepts, open issues motivations, properties and even future directions list various imperatives through a mind map (as shown in Fig. 1).

The cloud is designed to provide a vast scope of deployment, viz., on-demand services – always on, anywhere, anytime and anyplace. It is enabled by providing very simple graphical interface or API (applications programming interface), where one pays only on use of the specific platforms [18]. Moreover, as these platforms hide details of the underlying infrastructure from users and applications, and even the complexity, total privacy is promised. Thus the manufacturing facility of tomorrow may also be password protected, as the physical facilities get fairly distributed across the world. A soft lock to resources gives tremendous amount of security, traceability, and 24×7×365 operability/control. Apart from such advantage, the cloud + manufacturing synergy is deemed to bring consistently high efficiency and flexibility to the manufacturing industry, which all signify its high employability in manufacturing of tomorrow, which is already under a threat of severe recession [19].

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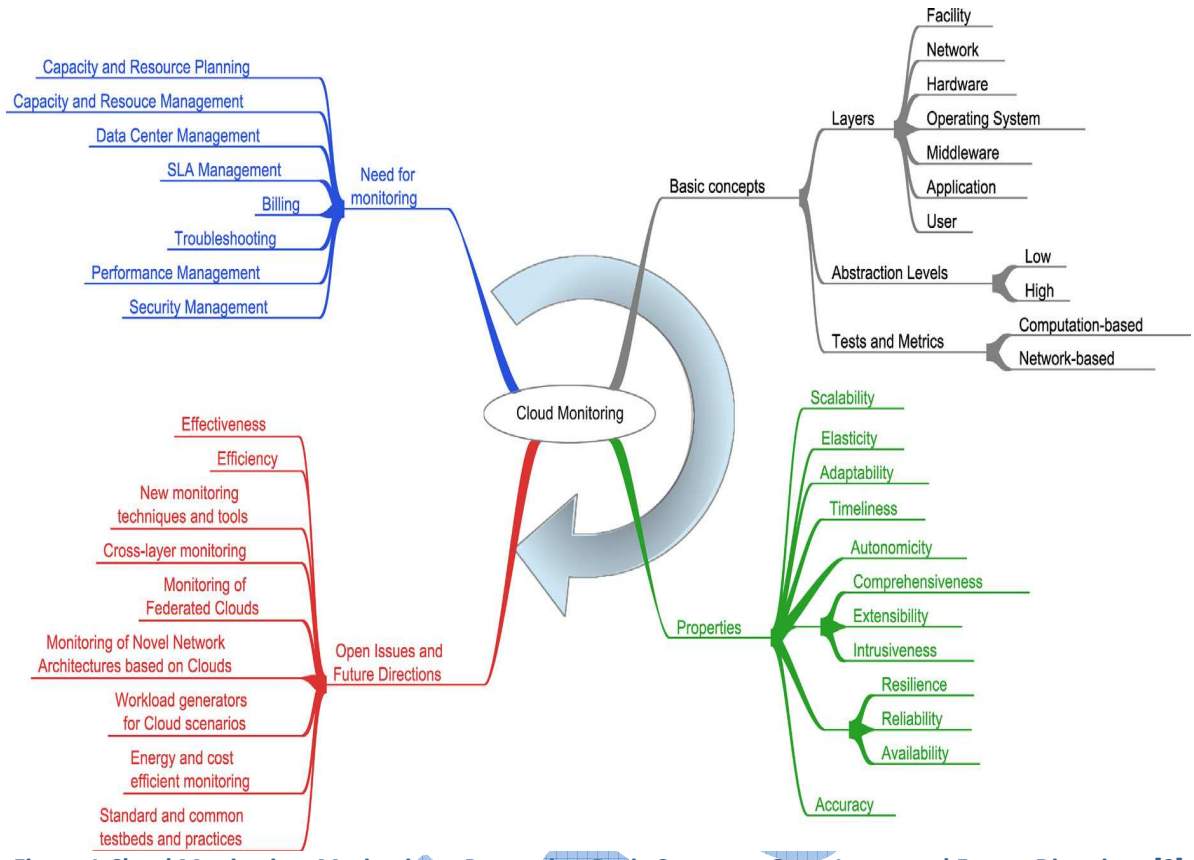

Figure 1.Cloud Monitoring: Motivations, Properties, Basic Concepts, Open Issues and Future Directions [9]

The deployment of cloud into manufacturing is attributed to the pull, both because of hard reasons of collaborating technologies and facilities that empower manufacturing for a new hope which must feed the quality of life as promised by manufactured products. Lately, service sector has been threatening manufacturing sector so as to snatch the coveted importance of the latter, though it is the latter which adds main value to the economy. Thareja terms it as enriching net worth, and supports it through verse [20]. In essence, the cloud manufacturing spells a new impetus to advanced manufacturing, with eased inputs to high success. Through following lines quote from the verse at "thareja.com" the role becomes clear:

When losses and threats are queer?
The engineer wields the pleasures,
To society, and in it welds all the gaps;
S/he provides a quality infrastructure.

Concurs Wang commenting on the operability of manufacturing over easing of inputs through virtualization [21] over a "compelling paradigm for managing and delivering services over the Internet in various industrial and commercial fields…[this new evolution of] cloud manufacturing helps in virtualization." The latter is a key technique to achieve performance in a multi-tenant system facilitated as these multiple virtual machines share the same physical devices [22]. As the clouds are cleared over the paradigm, the pathway for more realistic and implementable solutions starts emerging after a while.

Sharing is the mantra for new theme of tomorrow's advanced manufacturing, where hard facilities are all on call the soft way from cloud, and a flexible collaboration is the key to that sharing. To ensure the new transition is seamless, defining of prescriptive technologies is in vogue. Preempting possible issues in collaborations, Wang et al. [21] reviewed the approaches to conflict resolution, team, project management for a successful engineering design in a collaborative environment. They also outlined the methodologies, architecture and tools developed, now usable, for integration into manufacturing systems.

Changing Paradigms of Technology Involving Cloud

Proverbial *change* is the process that defines the wellness of current technological revolution (CTR) [23]. The latter, (i.e. CTR), is defined by the state of current technology with all the imperatives of improvements applied to it through a rigorous process of translating beliefs (paradigms) into measures realizing these advancements [24].

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A previous work [24] of the principal author attempted to sketch the imperatives and their complex roles (as in manufacturing and processing of spheroidal graphite cast iron) into the journey that meets the current state of market competition in manufacturing together with the change in technology evolution. The large change into CTR is now slated to be brought about by use of Internet, duly applied to the devices, and their control over the web. The need of adding value to manufacturing is devoid of any reservations, and the processes must be fueled innovatively [20]. Thus, the three constituents, namely, innovation, value addition, and cloud manu*future* are construed to build a new future state paradigm of manufacturing [20], which was titled as *innovaluation* [19]. Innovaluation was recently founded over the Joiner's paradigm of a triad involving value addition to maximize the manufacturing competition facilitated by innovation and Internet for collaborating necessary machines or infrastructure. Innovaluation was also paradigmed as an answer to manufacturing [19] towards the objective of zero defect, zero effect [25]. The profitability @ cost cutting is thus promised through this advanced wetware technology blessed by new valuation tools at the behest of information technology, and culture [3]. The modus operandi is schematically illustrated in Fig. 2. The former bases on capabilities, and the latter determines the growth directions to meet objectives of sustainability, and people alignment that pursue a lean, mean and green system of technology [23]. Meeting such an objective calls for a social change in thinking, and also a dynamic change in technology. The discussion on such requirements will be attended to later in this work.

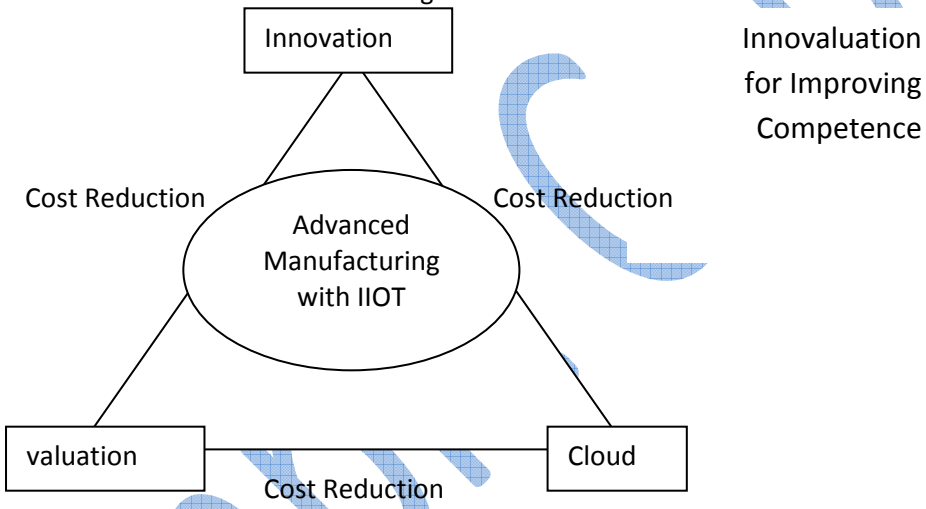

Figure 2.The Constructs for Success towards Make in India Modeled as "Innovaluation" through Cost Reduction by Innovation, Valuation and IIOT(Industrial Internet of Things) Adapted from [19]

The benefits of using cloud and Internet as stated above are immense, duly reviewed in Exhibit 1. Operational control-wise, the working parameters, condition of equipment and failures due to temperature, pressure or vibration exceeding beyond limits can be monitored remotely [22]. While manufacturers can assign each of their physical assets a digital identity that enables them to know the exact location and condition of those assets in real time ubiquitously throughout, the asset control may be exercised over the project duration independent of ownership. However, such innovations will come at a price, and call for inputs in technology, tools, and techniques – the two vital components in Joiner's paradigm. The operations, however, are guided over some paradigm of technology evolution as sketched by Barrett [27]. The end objective is a competency fit enough to justify 'just in time' production (at will and demand), through say mass customization techniques to maximize value @ design to manufacture to assembly (d2m2a) of engineered products.

The interfacing of technology evolution with innovation to generate value is in line with the initiatives of National Innovation Council, who asserts as objectives/ vision of the "Decade of Innovation 2010-2020"as [28]:

"The aim is to re-define innovations to go beyond R&D laboratories and factories to offer novel solutions that lead to inclusive growth for the people and by the people; foster appropriate eco-system across domains and sectors to strengthen entrepreneurship; focus on key drivers to ensure scalability, sustainability, durability and quality and expand the space for dialogue and discourse on innovation."

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The necessity of applying cloud technologies to manufacturing and assembly is thus reinforced as from the mandate of the National Innovation Council, which proposed innovation in present "Decade of Innovation 2010-2020". The citation is made from a report of Dun and Bradley which used Thareja's COMpro model of principal author. Later, Professor Okazaki Tetsuji of the University of Tokyo as quoted by Kojima [29] sketched the CTR scenario that is already attempting to connect even handheld devices for kind of impregnation of advanced manufacturing with alround innovations including those of cyber physical systems [5], and IIoT [19]. He states:

"The current technological progress in process is characterized by the exponentially greater performance of computers and other related devices, their digitization and combination-based innovation, and that the combination of these three characteristics is inviting the arrival of a new machine age."

Manufacturing and Assembling over the Cloud

Though cloud manufacturing is evidenced on the Internet/web resources, cloud assembly is hard to find. The initiative of allowing customers to build their own car has been attempted decades ago. For example, autobytel.com allows the option to build a car online. For the virtual car builder, the bandwidth is the limit. The autobyte claims people can "wax poetic about this new gadget until the proverbial cows come home, but why take our word for it? [they advise cutomers to] Click on the drop-down menu above to get started and make a car online – you don't even have to put on pants!"

Eventually, today's provisioning of cloud facilitates such designing to get disseminated further into the hands of individual buyers [30]. In a way with cloud, manufacturing and assembly invoke a pulled assembly or manufacturing wherein we can arrange different parts right with a scope of selection including designing and complete manufacturing over the cloud. By hiring more specialized people for designing/assembly for our project, we can not only gain command over market but also bargain for our work. By creating an environment where all information is available related to the plant, floor and the supply chain, the processes are made smarter. Cloud computing makes it possible that innovations are made vertical in various processes of modern enterprise, and thus support competitiveness by lowering the traditional barrier like cost, time, location and organizational boundary.

Cloud provides a platform for propagating the innovations, as well as the stimuli to integrate people processes and systems. In cloud-based solutions, the manufacturers are facilitated to access new capabilities faster because of the reduced setup time, cost, and complexity. These solutions let manufacturers experiment, share, and collaborate on new features and capabilities without much cost. Due to autonomous maintenance enabled, the availability of infrastructure is improved since it takes less time maintaining the product.

The manufacturers' leadership earned @ competition for design innovations notwithstanding, today, with the faster and higher demands of new and improved designs, companies are participating more often in global design chains and collaborations in order to gain competitive advantages [31, 32]. Research in collaborative design is focused on helping designers generate creative ideas and collaborate more efficiently and effectively by sharing design and manufacturing resources through formal and informal interactions [33, 34], thus encompassing all kinds of businesses; blurring the boundaries among plant operations, supply chain, product design, capabilities and ambitions @ demand of the product, smart manufacturing promises enterprises full visibility that supports all kinds of processes and products according to requirements and demand. The initiatives for modernization of cars has been taken up in separate works [35, 36]

Fuh et al. [37] classify two research avenues in collaborative design, namely, web-based design and agent-based design. Former provides:

1. Access to catalogue and design information on components and sub-assemblies;
2. Communication among multidisciplinary design team members in multimedia formats; and
3. Authenticated access to design tools, services, and documents [37].

On the other hand, in agent-based design, an agent approach allows developers to focus on objects rather than functions, thereby providing applications that are modular, decentralized and changeable [37].

However, two research issues have not yet been fully addressed, viz., various stakeholders (such as customers and designers) may not be able to participate in collaborative design effectively in various design phases, and inability to leverage collective intelligence and openness that could help generating creative design ideas and reduce time-to-market.

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The Exemplar of an Automobile Manufacturing and Assembly over the Cloud

The web site of Plex Manufacturing Cloud claims it is built on a single source of truth – from the plant floor to the top floor – so you can run an efficient automotive manufacturing. Because of the single unified platform that helps one manage ones manufacturing operations with unmatched agility and superior performance, Plex claims to deliver a competitive edge to businesses through its built-in broad and deep set of functionalities.

Following the discussions that cloud manufacturing helps design products competitively, conforming to customer's needs, and from a just in time point of view, the due potential of technology is endorsed. The strategy advises manufacturing to be managed not by changing whole of production line, but only by changing relevant components. In the following discussions, we exemplify through the manufacturing of an automobile [39] that has different subsystems, and each of them competitively developed to illustrate as to how advanced technology may be used for cloud-based designing and assembly.

For controlling different operations individually, or various steps of manufacturing processes together or holistically, from anywhere, and any time, manufacturer may assign different persons function over different operations as per preferred choice or production planning and control (ppc). Operations like engine assembly, gearbox assembly, etc., can be flexibly carried out and paid for suitably, according to work load or project complexity. Assembly (including various operations sketched as in tree diagram, Fig. 4) too gets software based, service hosted and provided over the Internet. Browsers, hosted by a third-party, are used to manage inventory management systems accessed using Internet-enabled device, through software, platforms and data storage. One of the great advantages cloud computing offers is overall reduction in costs and setup. As the software manufacturers use is hosted by a third party, there is usually no need for installation at manufacturer's end.

The present concerns of cloud manufacturing hover around reliability. The processes are at the behest of effective folder management as in case of any computer operations. Given, the moment one creates and downloads assembly over the cloud from different customers/ people/ designers all from different locations, for which the cloud data drive at the folder containing the selected assembly is launched, it simultaneously opens a dialog where the destination folder on physical computer or handheld device is specified. Once a selection is made, the download begins in the cloud data drive. For manufacturing businesses that have a number of warehouse and shop locations, the ability to access such software from any location with minimal setup or operating is enabled. The combined use of mobile devices and cloud-based applications is providing an edge for total businesses integration and maturity.

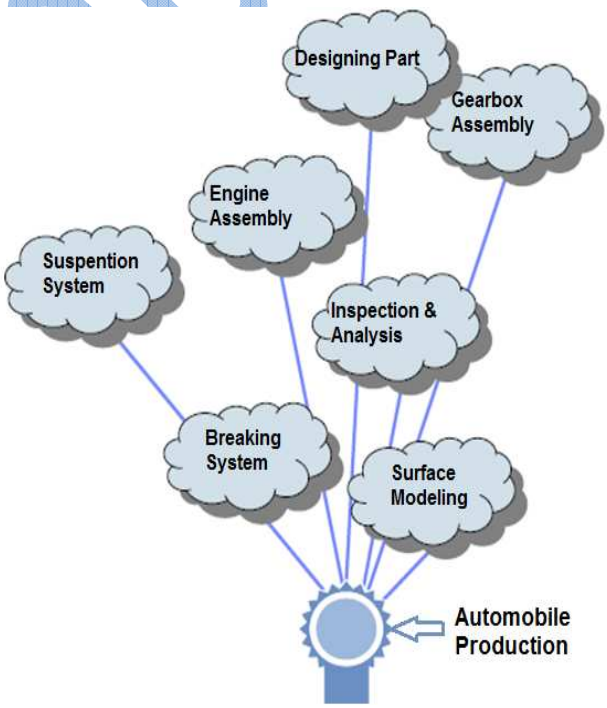

Figure 4.Various Functions in Automobile Production that are Manageable over Cloud

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One of the websites that is working on the 'pay to work' is Freelencer.com. Cloud has power to change the way products are made, control development cycle as well as create a smooth supply chain. Many industry leaders have started benefitting from full use and improved automation in their private data centers. Manufacturers are approaching cloud providers or systems integrators to simplify their cloud journey of resourcing needs or for optimizing their operations and focus on business. Innovation has played an important role in development and valuation.

The Yet Open Issues

Any design of solution to beat competitive forces can be focused on finding new ways to enhance product design and manufacturing. Since cloud manufacturing offers cheaper and on-demand access to cloud labor, a generalized set of tools and best practices without any upfront costs, it offers sufficiently large unexplored potential. As manufacturing enterprises become increasingly concerned with meeting the dynamic requirements of a global marketplace, capturing, and sharing product-related information and knowledge along with reusing design and manufacturing resources in globally distributed settings has become a key challenge [40, 41]. Further, in addition to the reliability issue, there are more limitations in vogue. Cloud factory in reality is a factory, in the cloud, where manufacturing and assembly lines are being brought into the digital age. Any digital task that can be consistently reproduced with a precision and correct output is solicited unambiguously, and without errors. The excerpts from eNVVY [42] emphasizes effecteness. It thus advocates a need for machine learning and matching algorithms to properly manage a large and distributed workforce.

Yet, an engineer deploys technologies,

For accuracy, performance & reliability,

Analog better differentiates frequencies,

But, alas! Devoid of Digital's security,

Yet, Digital further farther carries,

Unless one achieves in it good clarity.

The pangs favor only consistencies!

The advantages of discrete manufacturing capabilities are enumerated as under [43]:

- Reduce errors and improve quality with direct connectivity to shop floor automation.
- Leverage a unique, touchscreen control panel for capturing production, maintenance and tooling data.
- Enable operators to resolve production issues in real time for greater productivity.
- Access production data from anywhere using mobile devices through say providers like Smart Plex.

Well, we know, advanced manufacturing is related with terms such as 'automation', 'robotics' and 'computer technologies'. This all is facilitated by digital thinking. Research shows that manufacturers are relatively committed to these technologies. Currently, 47% of middle market manufacturers indicate use of at least one advanced manufacturing technique. The techniques most commonly leveraged include automation; computer technologies such as CAD, CAE or CAM; process technologies and information technologies. Thus from a critical evaluation of the competencies that promise knowing all the typical algorithms and statistics in the world, we suspect there sustain issues which still concern capability versus ambition [35], viz., matching imperatives that justify the handicap in humans performed work that machines do not threaten with.

It is feared that this open approach is pretty disruptive to an industry that often requires either a lot of money or time before getting started. Quality results come by finding talented and motivated workers, training and testing them, matching them with the work they are good at and like, giving them clear instructions and doing intelligent quality checks [44]. And all these factors deserve due alignment to quality thinking, learning and preparedness to use conventional wisdom and tools as specified say in Fig. 2, and the transformation (metamorphosis). This is advised as per Thareja's AUM model [45]. Application of right skills and processes helps deliver results as per need. The need is to support technology which is easier, dependable, reliable, and profitable, using disparate resources, facilities, much more flexibly, yet with an integrateability that can allow strategizing [4]. It is feared that this open approach is pretty disruptive to an industry that often requires either a lot of money or time before getting started. Quality issues also are expected in finding talented and motivated workers, training and testing them, matching them with the work they are good at, managing processes based upon provision of clear instructions, which are in turn influences by character of facilities in the cloud, doing intelligent quality checks and so on [46]. The journey is thus seen to repeat history, as the one that was visualized getting back as in a spiral.

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Earlier, when Henry Ford took a complex problem of building a car that could only be done by a team of highly skilled engineers all working on building one car at a time, industrial engineering assisted advances in technology facilitated breaking down all the tasks of building a car into many sub-steps that could require less skill at each step and so more people could do the work. This gave rise to a line assembly technique.

The schema is seen to turn full circle in cloud manufacturing. Cloud labor could really follow in the same footsteps as by building cars earlier way, and thus more production and higher quality could result from people that can do specific tasks with less training, and more so when their work is not so specialized. Thus, enabling businesses to deploy easy tools that are not only competitive but also competent in work system [46] that are made simplified with CTR is the mantra of success. Methods that emulate the idea of breaking work down to get more results and higher quality, with a simple pay-as-you-go model alongside, is the solution that is pursued simultaneously equipping computer-based work, is the key which is likely to revolutionize tomorrow's manufacturing.

Conclusion

In this article, we explored how to integrate clouds, digital thinking and advance manufacturing to reach out to our required expectations. For ambitious designing and assembling, different kinds of software with specified specialties are being deployed, even over the Internet. Today, the things can be resourced over cloud, designed and assembled or produced as per need or will. Researchers and practitioners from the industry are continually targeting newer and newer initiatives to remain competitive in the area of product design and manufacturing. Many of these efforts have focused on new ways to enhance product design and manufacturing from the perspective of information and resource sharing. The manufacturing enterprises target meeting the dynamic requirements through sharing product-related information and knowledge globally distributed settings. It is because the information technology (IT) sector at large has significantly aligned for providing on-demand self-services through location-independent resource pooling. The challenges of reusing of design and manufacturing resources in conditions of rapid elasticity, pay-per-use, are being met, and even succeeded. One particular benefit is that cloud manufacturing allows for faster and more flexible development and implementation of IT solutions as compared to traditional infrastructure and service models. There are troubles in the traditional models at peak loads, or for the maximum utilization. Since in context of cloud assembly and manufacturing, we are charged on a usage basis, not only the innovations are shared without the threat of disruption, the costs thereof remain low. However, the unit cost of on-demand capacity may be higher than the unit cost per time unit of fixed capacity. This gives advantage by not having to pay for the resource when not in use. With such advantages, the graduation to such new skill set involving cloud should be the agenda of research in tomorrow's manufacturing and production functions.

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