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Implementation of Machining on the Cloud: A case study in PLM environment

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Abstract. This paper focuses on the implementation of cloud solutions in the field of machining which is encompassed by the much larger field of manufacturing. Machining is the process of material removal to transform raw materials into final desired shape while manufacturing is the creation and assembly of components & finished products for sale. With the advent of new technologies, a lot of advancements have been made in the field of machining in the last few decades. We are seeing an explosive growth in the field of information technology and the world is more connected than ever before. The current scenario calls for manufacturers to change the way they perform operations by using cloud services rather than installing & customizing the softwares within their own organizations. This paper examines the intersection of the fields of machining and cloud computing to propose solutions for revolutionizing the way machining is done. After performing tests that involve machining simulations and creation of a collaborative working space to exchange data, we can conclude that it is completely feasible to perform machining operations on cloud. The findings of this study give an insight into the adoption of cloud technology in the machining field and provides useful information to industry professionals wishing to implement cloud solutions in their businesses and to scientists wishing to undertake work in this field.

Keywords: Machining, Cloud, PLM

1. Introduction

With the advent of new technologies, researchers and industry professionals constantly strive to look for new ways to innovate in the field of design and manufacturing. It has become a challenge to meet the dynamics of today's marketplace in the manufacturing field as the product development processes are geographically spread out. With the developments in the field of Information Technology (IT), efforts are now directed towards making advancements in the field of design and manufacturing by using IT tools & PLM concepts. We have noticed that cloud computing has brought a revolution in the field of information technology sector due to its distributed network access, flexibility, availability on demand and pay per use services. The potential advantages of applying cloud computing technology in the field of machining is coming into picture and a research work for implementing the cloud technology in IT field is needed. The idea of performing machining on cloud is still in its infancy but the industries are striving an effort to move to cloud rather than using the traditional ways as soon as possible. The organisation of the research paper is done in the following way: we first shed light on the concept of cloud computing & manufacturing, the developments that have taken place in the machining processes, the collaborative & distributed manufacturing on cloud and industry of future. After this, we have demonstrated that machining on cloud is feasible through our tests and finally, the conclusions and the future work to be performed are highlighted.

2. Literature Review

2.1. Cloud Computing

The word *cloud computing* came into existence in the year 2007 but the concept behind cloud computing find its roots in the 1960s [1]. National Institute of Standards and Technology (an industrial standard), defines the cloud computing as: "Cloud computing is a model for enabling ubiquitous, 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 interaction"

[2]. Cloud computing is derived from concepts like virtualization, service oriented architecture and software as a service and is defined as providing computing resources (i.e. software and hardware) to individuals and businesses on demand over the internet on a pay per use basis. Cloud computing is made up of three key elements: Large scale data centres hosted on remote servers, Services (software and hardware resources provided over the internet), Low cost computers and other web-enabled devices like laptops, smartphones etc. Cloud computing is an innovation and has got different meanings when seen from different perspectives. According to the technical perspective, cloud computing has evolved a lot from simple machines used for calculation to utility, grid and finally cloud computing. From the business viewpoint, cloud computing is a breakthrough which is changing the way the information technology resources are deployed and is creating new business models.

There are principally three types of clouds: Public, Private and Hybrid cloud [3].

In a Public cloud, access to resources is provided over a public network by companies that own and operate them. There is no need to purchase hardware, software or any supporting infrastructure and resources can be accessed from anywhere over internet.

Private cloud, on the other hand, is operated solely for a single organization and it provides highly automated management and control of resources. It is managed internally or by a third party and is preferred by classic IT as in private cloud there isn't a real change in governance.

Hybrid cloud combines features of both public and private cloud and allows to keep critical applications & technical data on private cloud and less sensitive data on public cloud.

Apart from different types of clouds, there are three types of cloud computing services, namely, Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) [4].

In SaaS, a pre-made application, along with any required software, operating system, hardware and network is provided. Applications run on distant computers on the cloud and the users connect to them through internet/web-browser. There is no need to purchase, install, update or maintain the software.

In PaaS, an operating system, hardware and network are provided and the customer installs or develops the softwares and applications. Thus, PaaS provides an environment based on cloud to deliver web based applications.

Lastly, in IaaS, only the hardware and network are provided and the customer installs or develops the operating systems, software and applications. So, computing resources including networking, storage, servers and data centre space are provided on a pay per use basis. The figure 1 below gives a clear & concise view of how different components of the system are managed for different types of cloud computing services. The benefits of cloud services include massive reduction in capital expenditure, getting away with the complexity of operating computers & networks and performing more efficient computing by centralized data storage, processing & bandwidth.
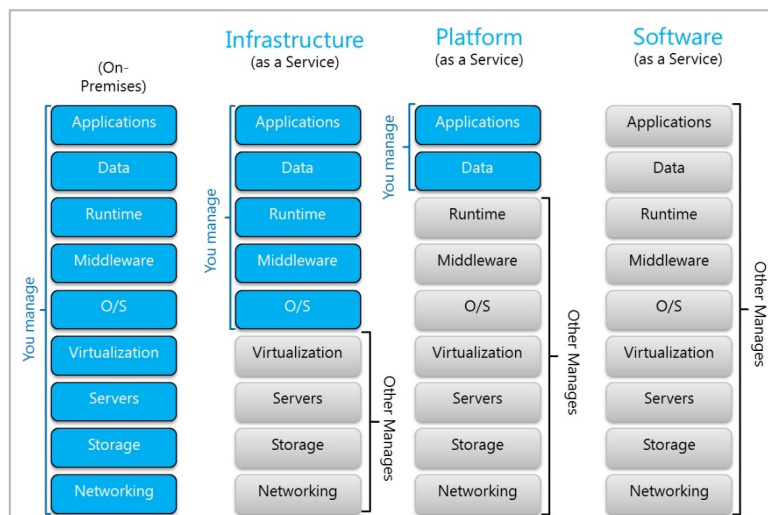

Fig. 1. Cloud Services Types [5]

Thus by using cloud services, we can transfer the responsibility of running hardware & software within the organization to the internet. The table 1 below highlights some of the research work done in the field of cloud computing.

Table 1. Research work performed in the field of Cloud Computing

Author	Subject of Discussion
Bayramusta, M. & Nasir, V. [6]	Evolution of cloud computing and the benefits & challenges related to cloud computing adoption.
Ratten, V. [7]	Proposition of the use of social cognitive theory in continuous use intention of cloud computing services.
Kim, W. [8]	Discussion on the adoption of cloud computing services & the associated technical issues.
Buyya, R. et al. [9]	Proposition of an architecture for creating cloud with market oriented resource allocation by leveraging technologies like Virtual Machines.
Abadi, D. [10]	Examination of the limitations & opportunities of deploying data management on the emerging cloud platforms.

2.2. Manufacturing on Cloud

This paper deals with the concept of machining on cloud but considerable amount of work can be found on the much larger domain i.e. Manufacturing on Cloud. Cloud Manufacturing is a customer-centric manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, reduce product lifecycle costs, and allow optimal resource loading in response to variable demand based customer generated tasks [11]. Cloud manufacturing is a concept that is entirely based on the concept of cloud computing. Li et al. [12] first used the term cloud manufacturing in the year 2010. Besides Li et al., Zhang et al. [13], Wu et al. [14], Schaefer et al. [15] and many others have also proposed definitions of cloud manufacturing.

The idea of providing manufacturing services on the internet was in fact developed a long time ago. Researchers envisaged the propagation of internet technologies in the production process and its potential benefits to significantly change the environment of industrial firms in the last few decades and many web based systems have been developed since then to sustain collaborative activities in different lifecycle phases of product development. Internet or web technologies have been continuously used to integrate these distributed lifecycle activities of the product development into a global integrated environment and considerable amount of work is available that explores the concept of using web services for manufacturing. The table 2 below provides a list of some of the research work done on the concept of providing manufacturing as a service.

Table 2. Research work performed on the subject "Manufacturing as a Service"

Author	Subject of Discussion
Goldhar et al. [16]	Future implications of Computer Integrated Manufacturing
Rajagopalan et al. [17]	Implications of the internet for design and rapid manufacturing technologies
Erkes et al. [18]	Implementation of manufacturing services available over the internet
F. Tao [19]	Key advantages and challenges of implementing Cloud manufacturing
L. Zhang [20]	Cloud manufacturing as a way to solve bottlenecks in the manufacturing field
G. Terrazas [21]	Cloud manufacturing as a service concept

Cloud based services have the ability to provide new methods of innovation, engineering design, and manufacturing that were not possible in the past. The concepts of mass collaboration, distributed design, and distributed manufacturing propelled by the Internet are now actually realizable for the next generation of product design and manufacturing. The table 3 below highlights some of the research work performed in the field of Collaborative Design & Distributed Manufacturing.

Table 3. Research work performed on subject "Collaborative Design & Distributed Manufacturing"

Author	Subject of Discussion
Valilai, O. & Houshmand, M. [46]	Development of an integrated and collaborative manufacturing platform to support a distributed manufacturing system using a service-oriented approach based on the cloud computing paradigm.
Wang, X. et al. [47]	Development of a cloud based manufacturing system to support ubiquitous manufacturing which provides a service pool that maintains physical facilities in terms of manufacturing services.
Andreadis, G. et al. [48]	Examination of the role of collaborative design in manufacturing in the era of cloud

	computing and proposal of a specific architecture with different servers for the implementation of a collaborative cloud based design system.
Wu, D. et al. [49]	Study on applications of cloud computing paradigm in product design & manufacturing and exploration of the potential of utilizing cloud computing for selected aspects of collaborative design, distributed manufacturing, collective innovation and virtualization.

2.3. Machining Technology Developments

As mentioned earlier, manufacturing is a global term that encompasses machining and for our study, we have focussed on the machining domain only. In this section, an overview of the advancements made in the machining processes to realize innovative product concepts have been underlined. With the advancements of technology, machine tools have been used to produce desired work piece shapes by controlling relative movements of work piece and machine tool. The developments in NC systems have made it possible to machine sophisticated parts with high accuracy. There are numerous methods to perform machining and considerable amount of literature can be found on the methods that are available today. Considering the scope of this study, we have discussed the principal machining operations and highlighted the research work performed in these fields in the form of tables.

2.3.1 Turning

Turning is one of the most common metal cutting operation. In turning, a work piece is rotated about its axis while a single-point cutting tool is fed into it, thus, shearing away unwanted material and creating the desired part. Turning can occur on both external and internal surfaces to produce an axially-symmetrical contoured part [22]. During turning operation, a piece of relatively rigid material is rotated and a cutting tool is traversed along 1, 2, or 3 axes of motion to produce parts of precise diameters and depths. The turning processes are typically carried out on a lathe and can produce various desired shapes.

Table 4. Research work performed on subject of Turning

Author	Subject of Discussion
Phillippe Revel et al. [23]	Proposition of a high precision hard turning operation for finishing of AISI 52100 bearing components.
Kadir Gok [24]	Development of a three-dimensional finite element model to calculate the process parameters for turning operations.
V. Vijayaraghavan et al. [25]	Proposition of a finite element based data analytics approach for modelling turning process of Inconel 718 alloys.
Hemant Jain et al. [26]	Proposition of a method for optimisation and evaluation of machining parameters for turning operation of Inconel-625.
Brecher, C. et al. [27]	Investigation of the optimal process parameters for parallel turning operations.

2.3.2 Milling

Milling is the process of machining flat, curved, or irregular surfaces by feeding the workpiece against a rotating horizontal cutter containing a number of cutting edges. The milling machine basically consists of a motor driven spindle, which mounts and revolves the milling cutter, and a reciprocating adjustable worktable, which mounts and feeds the work piece [28]. The milling process removes material by performing many distinct & small cuts. This is accomplished by using a cutter with many teeth, spinning the cutter at high speed, or advancing the material through the cutter slowly. Mostly, a combination of these three approaches is used to remove material.

Table 5. Research work performed on subject of Milling

Author	Subject of Discussion
Mu-Ping Tsai et al. [29]	Exploration of the usage of milling process to mill thin walled conical and tubular work pieces.
E. Budak [30]	Study of the analytical force & stability models to optimize the milling process & achieve improve part quality & productivity.

S. Warghat & T. Deshmukh [31]	Optimization of the machining parameters for end milling operation.
Owodunni, O. & Pinder, D. [32]	Sustainability improvement in milling operation through improved tool design and optimized process parameters.
A. Garg et al. [33]	Modelling of a milling process by a complexity based evolutionary approach.

2.3.3 Drilling

Drilling is the process of producing round holes in a solid material or enlarging existing holes by using multi-tooth cutting tools called drills or drill bits. Various cutting tools are available for drilling, but the most common is the twist drill [34]. Drilling is one of the most complex machining processes and the principal characteristic that distinguishes it from other machining operations is the combined cutting and extrusion of metal at the chisel edge in the center of the drill.

Table 6. Research work performed on subject of Drilling

Author	Subject of Discussion
Chatterjee, S. et al. [35]	Investigation of the simulation and optimization of machining parameters in drilling of titanium alloys.
Giasin, K. et al. [36]	Experimental study on drilling of unidirectional GLARE fiber metal laminates.
Etienne Robert Perrona et al. [37]	Exploration of the possibility of drilling of high quality features in green powder metallurgy components.
Biermann, D. & Kirschner, M. [38]	Experimental investigations on single lip deep hole drilling of super alloy-Inconel 718 with small diameters.
Khashaba, U. et al. [39]	Machinability analysis while drilling woven GFR/epoxy composites.

2.3.4 CNC Machining

CNC (Computer Numeric Control) is a process that involves the use of computer to control the machine tools. The tools that can be controlled in this manner include lathes, mills, grinders etc. In CNC Machining, numeric control is used to control the machine tool. A customized computer program is written for an object and the machine is programmed using CNC machining language (called G-code) that controls all the features like feed rate, coordination, location and speed. It is possible to control exact position and velocity of the machine tool using CNC and it can be used to manufacture both metal and plastic parts. [40].

Table 7. Research work performed on subject of CNC machining

Author	Subject of Discussion
Linjian Yang & Jinchun Feng [41]	Research on multi-axis CNC programming for machining large hydraulic turbine blades.
Safaieh, M. et al. [42]	Proposition of a novel methodology for cross-technology interoperability in CNC machining.
Newman, S. et al. [43]	Study of the process planning for CNC machining to make it more energy efficient.
Zhu, Y. et al. [44]	Study on tool orientation & optimization for 3+2-axis CNC machining of sculptured surface.
Soori, M. et al. [45]	Investigation of the dimensional and geometrical errors of three-axis CNC milling machines in a virtual machining system.

Research work highlighted in the tables above gives an idea that work is being continuously done in the field of machining. Today, industry professionals are facing challenges that didn't exist in the past. The world is going faster and is more connected than ever before which provides new opportunities & risks. The current situation demands for a change in the way machining is performed and cloud services provide a great opportunity to achieve it. The intersection of cloud computing & machining field can help in tackling problems like: how to accelerate time to market, how to optimize design & machining time, how to work together using a collaborative platform, how to increase resource utilization, how to instantly access machining solutions and how to reduce capital cost & complexity. This paper addresses the need for implementing cloud services in the field of machining in order to allow data exchange, designing, machining & simulation over geographically distributed

network. In this study, by using a cloud based collaborative platform to exchange data and perform machining operations & simulation, we have shown that concept of performing machining on cloud is achievable and we are not far away from implementing these solutions in the real world.

2.4. Industry of Future: A viable platform for deploying machining on cloud

French government's initiative "Industry of Future" [50] launched in 2015 answers to the shortcomings that are present at the moment by helping companies modernize their production base by using digital technologies. The objective today is not to provide best product or service but to propose solutions that bring products and services together. The aim is to form a more connected, more competitive industry that responds to the needs of the customers quickly. The principal challenges to achieve this goal are: Developing cutting edge technologies, Encouraging & enabling digital transformation throughout the ecosystem of mid-sized companies, Transformation of companies business models, Upskilling the industrial workforce & training the employees to be proficient in using the new technology and Developing a collaborative platform for sharing the data & information. The French industry of future has aimed to develop solutions for nine priority markets, namely, Smart food choices, Digital confidence, Smart devices, Data economy, Medicine of the future, Tomorrow's transport, Eco-mobility, Smart cities and New resources. For the purpose of our study, we consider it as a viable platform to perform machining on cloud for the industries wishing to digitize their ways of machining as one of the principal aims of the Industry of Future platform is to develop a network of regional platforms to enable the companies to pool and test new technologies and train their workforce to use these new tools. Using the regional platform, pilot projects can be launched to bring together industrial players in the process of launching or planning to launch a project to share best practices and develop a unified collaborative approach. The Industry of Future concept involves building collaborative R&D projects to fill existing gaps in today's technologies and is based on convergence of factories, connected objects, robotics, cyber security and other technology that parallel the Machining on Cloud concept of digitization of machining methods of small and medium enterprises via innovative and collaborative platforms. Moreover, the scope and governance of Industry of Future project is designed in a way so as to ensure a natural interface with the German Industry 4.0 platform that aims to revolutionize machining processes by merging of the internet and factories, thus, leading to tools and workstations communicating constantly via the internet and virtual networks. Industry of future like German Industry 4.0 is also based on total reorganization of the mode of production by using existing tools and placing greater reliance on collaboration over networks.

3. Machining on Cloud Using a Collaborative Platform

In the last few decades, numerous developments have taken place in the domain of machining-ranging from simple operations on a lathe machine to complex program based operations on CNC. Cloud computing is continuously revolutionizing the computer systems and is providing greater dynamism and flexibility to a variety of operations. Cloud computing has occupied a significant position in the IT industry and its implementation can be seen in different sectors & industries. Despite its omnipresence, cloud computing services haven't been used in machining field yet and a major technological shift can be brought by using cloud services for performing machining operations.

The way machining operations are performed today are quite efficient and a lot of advancements have been made over the years but they lack the ability to allow users (designers etc.), who are geographically spread out, to work in a collaborative environment, which can be made possible by cloud computing. Working collaboratively on a common platform on cloud will provide more agility & capability to work in real time, thereby, allowing exchange of data & information easily to drive profitability.

As discussed earlier, researchers have already explored the concept of collaborative design & manufacturing on cloud in the past. The work presented here focusses on machining domain and deals with the creation of a collaborative working framework on cloud to answer the problem of lack of a collaborative environment for users who are geographically spread out. Collaborative environment can be accessed on cloud to get data and perform simulations to visualize everything digitally before actually going into the production phase, thus, optimizing the overall process.

As a part of the study, we also performed both face to face interviews & filling of a survey form to take into account the perspective of manufacturing industries (particularly SMEs) and investigate what is preventing them from using cloud services for machining operations even though they are using it for other purposes. From the results of the survey, we found that the industries are quite familiar with the cloud computing technology and are willing to adopt new technology to save money but are hesitant in adopting it due to the following principal reasons: Lack of confidence in the successful implementation of cloud services, Concerns over data security &

loss, Difficulty in learning & using Cloud Technology, Cloud service availability issues and the Cost of using cloud services. Through our study, we have tried to answer the concerns of the industry professionals by demonstrating that it is feasible to perform machining on cloud using a collaborative platform in a secure way.

3.1. Case Study: Implementation of Machining on Cloud at Dassault Systemes

In order to create a collaborative working space and perform machining simulations on cloud, we used 3DExperience platform (a platform used for performing CAD, PLM tasks) & DELMIA software (used for machining, simulation & operations) of Dassault Systemes. The test run was performed internally within the Dassault Systemes to demonstrate the successful implementation of cloud services for performing machining operations. The table 8 below lists the technical specifications of the performed test.

Table 8. Technical Specifications of the performed test

Technical Specifications	
Platform	Windows 7 64-bit Service Pack 1
Browser	Internet Explorer 11
Java	Version 8 Update 51
Cloud Service	3DS Public Cloud
Computing Service	SaaS service on 3DExperience Platform
Machining Software	DELMIA
Machining Role	NC Multi-axis Milling Programmer
Machining Application	Multi-axis machining

In our study, we have considered an industrial collaboration scenario between an OEM (original equipment manufacturer) and a Supplier. OEM gives the order to the Supplier to make the part and Supplier provides the machined part to OEM based on the provided data. The data exchange between the OEM and Supplier is done by creating a Collaborative 3D Space. A collaborative workspace or shared workspace is an inter-connected environment in which all the users at dispersed locations can access and interact with each other. Appropriate licenses & roles are allotted for the creation & management of the collaborative space and both the OEM and the Supplier are put on the same tenant (a tenant is a group of users who share a common access with specific privileges to the software instance). Furthermore, the visibility of the space is set to private so that a person who is not a member of the collaborative space can't access the data. Firstly, the OEM creates the 3D space & 3D Part and provides the data to the Supplier (Fig 2). In the scenario, the OEM can provide input as only a 3D Part, Process documentation (process, tools list etc. in pdf/excel format), NC (machine, tools, setup in 3D format) context or a combination of these inputs (Fig 3). After performing the allotted tasks, the Supplier provides the physical 3D part, NC (numeric control) code and 3D process as output to the OEM.
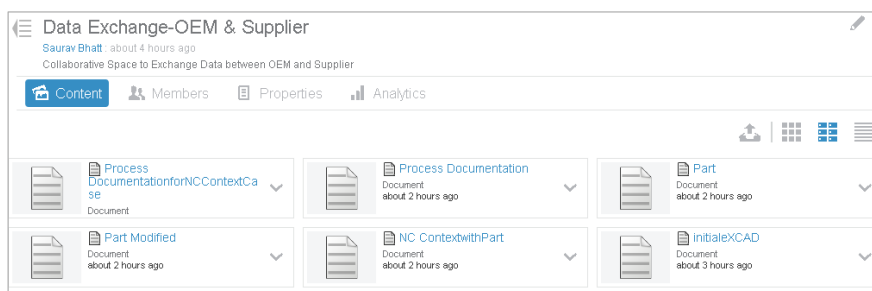

Fig. 2. Upload of data on the created collaborative 3D space by OEM

The process consists of importing the input 3D part in the platform and then creating a PPR context. A PPR context allows you to make a manufacturing context, which contains products, manufactured items, systems, operations, and resources. In order to define the PPR context, a mill tool assembly, a NC machine setup with reference axis systems are defined. The part is machined using a Power Machining operation and for that, all the required parameters like machining strategic & geometric parameters, feed rate, spindle speed etc. are carefully selected. After defining all the parameters, the tool path is computed and the simulation is performed to obtain the desired results (Fig 4). In the process, we have created only one Power Machining operation for the sake of simplicity but it is possible to perform any required machining operation like drilling, turning etc.
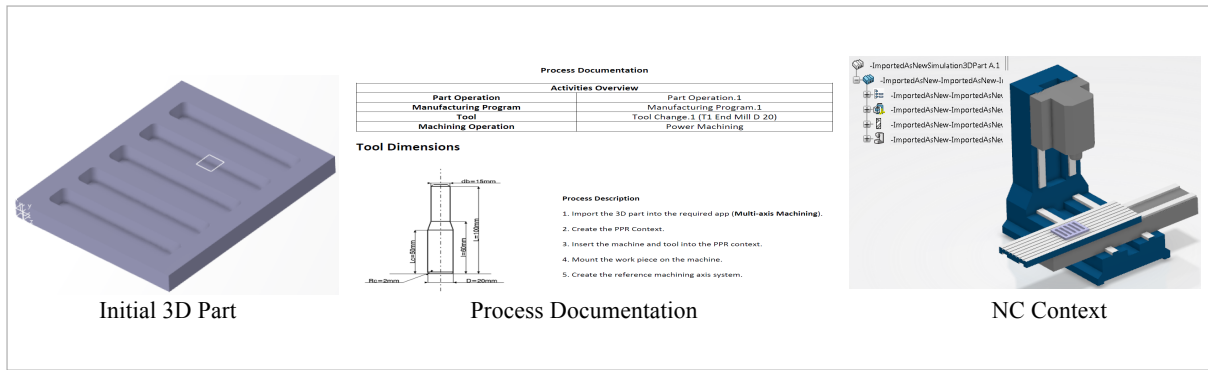
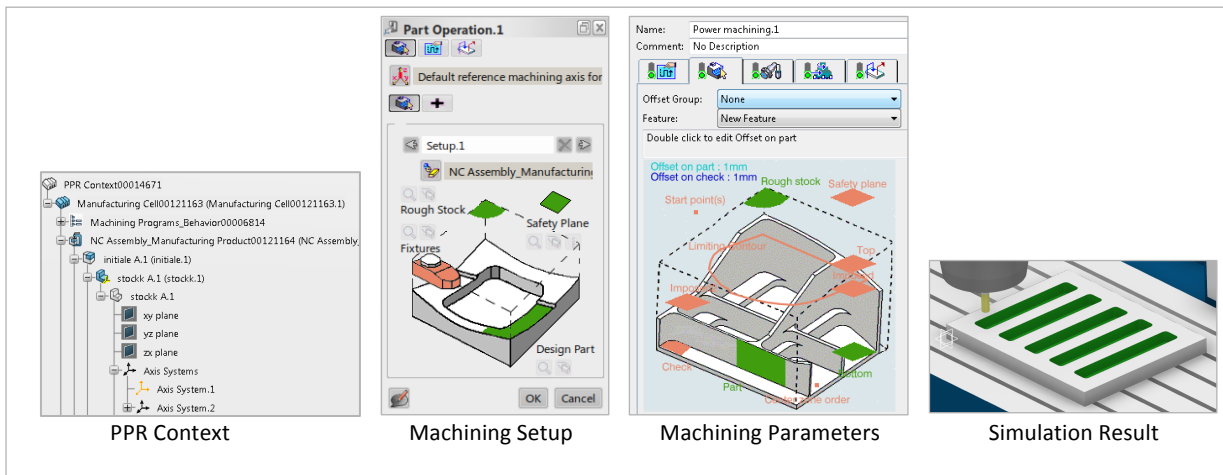**Fig. 3.** Inputs provided by OEM to Supplier

Initial 3D Part

Process Documentation

NC Context

Fig. 4. Machining PPR Context, Parameters & Simulation Result

PPR Context

Machining Setup

Machining Parameters

Simulation Result

Fig. 5. Outputs provided by the Supplier to OEM
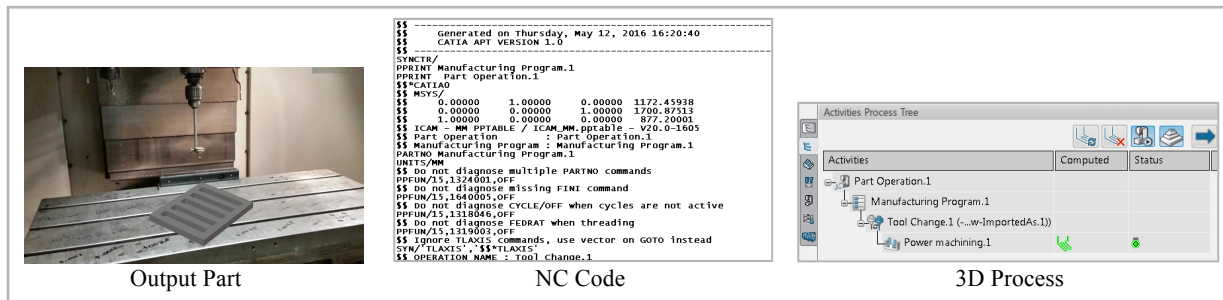
Output Part

NC Code

3D Process

After performing the simulation and obtaining the final 3D process, the Supplier uploads the output data (Fig 5) on the same collaborative space for the OEM (Fig 6). The management of data (machines, tools etc.) during the entire process is done using the product lifecycle management tools of the software. The results obtained after the successful completion of our test demonstrates that it is completely feasible to work in a collaborative working environment and perform machining simulations on cloud.
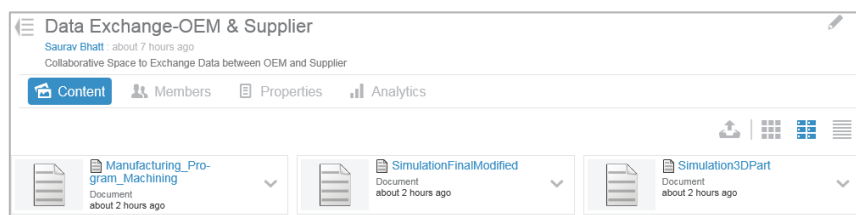

Fig. 6. Upload of data on the created collaborative 3D space by Supplier

4. Conclusions and Future Work

The concept of cloud computing has been around for some time but its implementation in the field of machining has not been explored yet. The work performed in this study examines the intersection of these two fields to provide industry professionals with cloud based solutions. The concept of collaborative work environment that allows the end users, who are geographically spread out, to work on a common platform is presented. The collaborative space is used to exchange data, make modifications in real time and perform machining simulations on cloud using different possible test scenarios. In addition, by doing a survey, we identified the perspectives of industry professionals and tried to answer their concerns through the outcomes of our tests. Further work consists of testing the work performed in this study with an external manufacturer (possibly through the medium of Industry of Future platform) to check the applicability of the proposed solutions in real world and to tackle the issues that might arise & make necessary improvements. Another improvement to this work could be creation of a dashboard to monitor the activity of an end user who is using machining applications on cloud and to measure the proper functioning of the proposed solutions. The findings of this study will be useful to the industry professionals wishing to perform machining operations on cloud by utilising a collaborative working platform.

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