Cloud Manufacturing as a New Type of Product-Service-System

Alberto Charro
Department of Mechanical Engineering
The University of Bath
Bath, United Kingdom
Tel. +44 (0)1225 386163
Email: alberto.charro@bath.edu

Dirk Schaefer
School of Engineering
University of Liverpool
Liverpool, United Kingdom
Tel. +44 (0)151 794 2082
Email: dirk.schaefer@liverpool.ac.uk

Cloud Manufacturing as a New Type of Product-Service-System

Industry 4.0 technology developments in Cloud Manufacturing are challenging traditional business models, and adapting these is key to a sustainable competitive advantage. In parallel, pay-per-use strategies are being discussed as an enabler to future sustainable societies. The general benefits of Cloud Manufacturing services are clear, but to date the actual business implications from a service provider perspective have not been discussed. This paper explores new business model opportunities based on the idea of providing Cloud Manufacturing as a completely new type of Product-Service-System. Technology developments and business recommendations are defined, considering the proposed business model targets the manufacturing industry as a whole. Manufacturers make use of their spare capacity by purchasing time on networked equipment on a pay-per-use basis. This allows costs to be brought down, whilst creating new revenue streams. It also increases machine hosts' competitiveness by reducing investment costs and enabling instant manufacturing scalability. Cloud Manufacturing is then classified into three levels of machine autonomy, arguing that as technology develops intermediaries may slowly integrate vertically and eventually replace manufacturers by completely autonomous equipment. The proposed business model presents both a first step and a baseline point of reference towards bridging the gap between advanced manufacturing technology and new business development in the context of Industry 4.0 (Smart Manufacturing).

1. Motivation and Introduction

Manufacturing industries have undergone radical change throughout history, categorised into industrial revolutions. The first (18th century) saw a shift from predominantly manual labour to production mechanisation. Steam powered machinery enabled a transition powerful enough to permanently disrupt western society, bringing ordinary people a sustained growth in living standards (Lucas 2002). The second, known as the technological revolution (20th century up to the First World War) introduced electrical power to manufacturing, enabling mass production and division of labour. The third (1970's), known as the digital revolution, brought production automation through advances in electronics. The introduction of robotics in production lines drastically increased speed, quality and repeatability, reducing costs associated to labour and waste.

Uneven paces of industrial revolutions around the world give rise to inequalities of lifestyle across economies that fail to adapt quickly (Flynn, Dance and Schaefer 2017). In order to prepare for these changes it is essential to be proactive rather than reactive. As demonstrated in previous industrial revolutions, modern business models must develop hand-in-hand with new technologies to remain competitive (Flynn, Dance and Schaefer 2017)

The manufacturing industry is on the verge of a 4th industrial revolution, a radical industry-wide technological change based on digitisation that affects all business activity in and beyond an enterprise. In this context, the more specific term Industry 4.0 (I4.0) refers to advanced integrated manufacturing systems whereby modular manufacturing equipment can communicate in real time with each other (or with humans) to analyse data, predict failures and reconfigure itself to optimise a

manufacturing network's value chain. It is enabled by cyber physical systems[1], the

Internet of Things[2] (IoT) and cloud computing.

Cloud Manufacturing (CMfg) has been identified as one of the key pillars for

realizing the vision of Smart Manufacturing (Xu 2012) (Wu, Rosen et al. 2015) in the

context of I4.0. Building on the paradigm of cloud computing, it aims to transfer a

network of vertically and/or horizontally integrated manufacturing resources into

capabilities and services which can be managed as a collective. It exploits a share-to-

gain philosophy rather than a traditional compete-to-win approach, enabled through the

Industrial Internet of Things and Services. If fully implemented, it may enable instant

communication between multiple geographically dispersed manufacturing facilities,

optimising a network's value chain through bespoke recommendations. A diverse

network of machines enables a wider range of manufacturing capabilities, based on the

exploitation of enterprises' individual competencies (Wu, Greer, et al. 2013). To date,

CMfg has been discussed mainly from a technical point of view (Wang and Wang

2017) (Zhang, et al. 2012) (Li, Zhang, et al. 2014).   However, a clear research gap

identified in the literature concerns the creation of new business models for CMfg from

the perspective of new and emerging I4.0 Product-Service-Systems. Traditional

manufacturing business models often fixate on the idea that production must take place

under the same roof or at a specific location. However, with the rise of CMfg, there is

an opportunity to devise completely new and potentially disruptive business models that

---

[1] **Cyber Physical System:** A machine controlled or monitored by an algorithm tightly integrated with the internet and its users.

[2] **Internet of Things:** A series of electronically connected physical devices that enable them to collect and exchange data.

better reflect the new opportunities of the digitised manufacturing sector (Schaefer 2017).

In this context, new Product-Service-Systems (PSS) are being discussed as a main enabler of future sustainable societies, with the ability to monetise products throughout their entire lifecycle. These models link the principles of pay-per-use to the functionality of the product, allowing companies to innovate, resulting in machine efficiency, ecological and financial improvements (Kerr and Ryan 2009). Attempting to build on this, such business models have not yet been defined for the new domain of CMfg and hence are the focus of this new line of research. This includes investigating which firms already implement CMfg-PSS of sorts (early adopters), what CMfg-PSS business models actually look like, the technological foundations for enabling CMfg-PSS, and best practices for the transition from traditional manufacturing to a PSS. Based on the preceding, an initial baseline CMfg-PSS business model for implementing CMfg-PSSs is proposed.

2. Literature Review

2. 1 Cloud Manufacturing

The term Cloud Manufacturing was first introduced in 2010 by Li et al (B H Li et al. 2010), but has since been adapted or interpreted in various ways (Wu, Rosen, et al. 2015). It is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g. manufacturing software tools, equipment and capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Xu 2012). Several authors have further categorised associated new manufacturing paradigms (Singh Srai, et al. 2016), with Wu et al. (Wu, Lane Thames, et al. 2012) (Wu, Rosen, et al. 2015) (D. Schaefer

2014) describing a holistic cloud-based design and manufacturing (CBDM) vision to address the entire product realization process as a whole. Here, everything required to take an idea from ideation to design to production may be realized on a service basis through the cloud, including:

- Hardware-as-a-Service (HaaS): Hardware rented through a CBDM environment

- Software-as-a-Service (SaaS): Software used without purchasing a full license

- Platform-as-a-Service (PaaS): Product development tools used on a CBDM environment

- Infrastructure-as-a-Service (IaaS): Computing resources made available to consumers without their need to purchase or maintain them

A complete CMfg system requires several critical technology developments, including real time resource monitoring through embedded sensors (Lindström, et al. 2014), as well as further use of cloud services for managing large supplier networks (Hosono and Shimomura 2012). However, whilst most CMfg research focuses on its technical fundamentals (European Union, H2020 Research Project n.d.) (European Union, CREMA n.d.) (European Union, C2NET n.d.) (ManuCloud n.d.), this article addresses the business perspective of providing CMfg services by bridging the current gap between CMfg and PSS, two domains previously unconnected but essential for new value creation opportunities in the digitised manufacturing sector.

2.2 Product-Service-Systems

PSS' are an evolution of traditional business models (Quinn, Doorley and Paquette 1990), monetising a product's capabilities instead of the product itself. If successful, they can fulfil a client's needs in a customised way, enhance relationships, encouraging innovation and stabilise long-term revenues (Tukker 2004). PSS' are known by under

several names including functional sales, functional products and Industrial Product-Service-Systems (IPS[2]) (Lindström, et al. 2014). With several popular definitions (Manzini and Vezolli 2003) (Wong 2004), a PSS is a system of products, services, supporting networks and infrastructure that is designed to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models (Mont 2001). Servitisation often involves absorbing some client tasks in an attempt to make the proposal more appealing, however it is only financially viable if the extra cost in offering the services is lower than the total perceived added value of the PSS by the client. Although companies often focus on technology leadership, customers are often concerned about paying for the best combination of product, value and solution. According to Meier et al. (Meier, Roy and Seliger 2010), PSS offerings that deliver value in an industrial application should cater for changing customer demands and allow for the partial substitution of the product or services over its lifecycle. It should ultimately lead to a better use of machine performance, allowing customers to concentrate on their core competences.

There are three main differences between products and services (Wallin and Kihlander 2012):

- Time: Products are produced and then used, whereas services are produced and used simultaneously (uno-actu-principle[3] (Meier, Roy and Seliger 2010)).
- Ownership: Whereas product ownership is transferrable through sale, service ownership is harder to transfer (excluding knowledge transfer).

---

[3] **Uno-actu-principle (Uno-actu-prinzip):** A German business theory term used to describe an important difference between services and products; services are simultaneously produced and consumed (in one act).

- Design: Products tend to be tangible with technical variables (dimensions, materials, etc.), whereas services tend to be intangible (time, place, etc.).

Baines et al. (Baines, Lightfoot and Evans, et al. 2007) developed the idea that PSS' can be classified into three main categories; "product", "use" and "result" oriented, later developed into eight sub-categories (Tukker 2004):

- Product Oriented (Product Related, Advice/Consultancy): Selling products with services designed around them (e.g. installation, maintenance, etc.). They add value by optimising existing resources, where consumers normally make the heavy capital investments.

- Use Oriented (Product Lease, Product Renting/Sharing, Product Pooling): Product ownership remains with the PSS provider, where multiple consumers share the products' use, paying accordingly. Offerings tend to require a high initial investment from the provider, but offer a low one for the customer, and an overall lower system-wide capital investment. These may come with environmental benefits due to larger utilisation (e.g. it is estimated that one Car2Go vehicle replaces up to eleven private cars (Martin and Shaheen 2016)). Users may experience lack of ownership or privacy with these services.

- Result Oriented (Activity Management, Pay-per-service-unit, Functional Result): Both the provider and customer agree on the desired results, where the product specifics are not defined. The provider will inevitably develop specialised knowledge in the field, giving customers access to high quality work at lower prices through economies of scale. These PSS' can foster innovation from the provider's side, although performance criteria and expected usage have to be strictly defined in advance to manage customer expectations.

While Xerox and Rolls Royce are two well-known PSS flagships due to their great innovative and financial successes, there are numerous other successful PSS' worth mentioning (Table 1).

Table 1 - Notable PSS enterprises

Organisation	Product Type	PSS Description
Xerox	Office Equipment	Leasing/pay-per-copy business model for office equipment. Xerox will install printers or staffed printing services in offices with fixed prices. The products are also designed for remanufacture, to reduce costs and environmental impacts. (Xerox 2017)
Rolls Royce	Aircraft Engines	Power-by-the-Hour service package for aircraft engines, whereby maintenance, repair and overhaul services are charged per hour of flight. (Rolls Royce 2017)
Atlas Copco	Mining Equipment	Mining capabilities are sold per m^3 of excavated materials. (Atlas Copco 2016)
Philips	Lighting Systems	Philips' pay-per-lux model promises a fixed price for a given building luminance, covering all maintenance aspects. (Philips 2015)
Michelin	Truck Tyres	Michelin offers transportation companies a complete tyre stock management system, charging per kilometre driven. (Michelin 2015)
Electrolux	Laundry Services	Offer a pay-per-wash service including equipment, servicing and detergent use. They additionally remotely monitor energy efficiency. (Electrolux n.d.)
Hilti	Professional Construction Tools	Hilti manages a fleet's construction equipment. They will organise the availability, maintenance, insurance and organisation of the tools for a fixed monthly fee. (Hilti n.d.)
Car2Go	Car Renting	Specially designed electric Mercedes-Benz/Smart cars are spread around several cities. Users can reserve them on their phone apps and are charged on a per-minute basis. They can leave the car anywhere in the city, with all fuel (they are electric vehicles) and parking covered by the company. (Car2Go 2017)

2.3 Opportunities for New Business Models

An in-depth literature review revealed that there indeed is a growing need for new business models surrounding the Industry 4.0 sector in general and Cloud Manufacturing in particular. Martinez et al. (Martinez, et al. 2010) discuss how both product and process-based manufacturing are easier to imitate by competitors than integrated PSS' (Dickson 1992), inferring that the integration of products with services is a source of sustainable competitive advantage. However, it takes time to build higher corporate profitability. Martinez argues that the benefits of PSS strategies may only be delivered in the long term, due to the need to invest in new skills, capabilities and technologies. The needs of the users therefore have to be well understood to develop

tailored offerings.

McKinsey & Company discuss the influences of I4.0 on Business-to-Business (B2B) operations (McKinsey & Company 2015). They estimate the transformation pace to be relatively slow due to long investment cycles and reluctance to change. However, they also note that although 80% to 90% of value created in prior industrial revolutions came from upgrading manufacturing equipment (through steam and automation), high investment upgrades are expected to account for only 40% to 50% with I4.0 technology. McKinsey found that technology suppliers, as well as manufacturers, generally view I4.0 as an opportunity rather than a risk (McKinsey & Company 2015). They also identified that US companies expect I4.0 to impact their business models more than companies in Germany and Japan, which may explain why the US have been more proactive preparing itself for these changes. Additionally, 80% of respondents from process industries, heavy/industrial machinery and discrete manufacturing expected it to impact their business models. They further argued that if annual productivity growth could increase by only between 1% and 1.5%, a compounding improvement over the next 25 years could raise US average incomes by between 25% and 40% compared to 2012 levels. Currently, approximately 46% of the global economy (£25.9 trillion in global output) could benefit from the Industrial Internet, of which $11.6 trillion (£9.3 trillion) are directly associated with manufacturing. If the rest of the world was able to secure half of the US' current productivity gains, they argue that the Industrial Internet could add between $10 and $15 trillion (between £8 and £12 trillion) to global GDP over the same 25 years. Securing a fraction of these productivity gains could therefore be significantly lucrative.

A successfully implemented I4.0 PSS must assess technology enablers and market readiness. In 2008 Baines et al. (Baines, Lightfoot and Benedettini, et al. 2009)

surveyed 55 UK-based manufacturing senior executives with turnovers in excess of £10 Million to determine the adoption of servitisation strategies. Over 95% of manufacturers surveyed were adopting "Product Oriented" PSS' and 25% were also involved with equipment monitoring and preventive maintenance. These demonstrate the slow integration of these systems in industry. The improved ability to respond to customer needs, as well as the desire to increase revenues were amongst manufacturers' motivations for offering services.

It is vital to identify which technologies have potential in the near future to design a relevant CMfgPSS. Gartner's 2016 hype cycle for emerging technologies (Gartner 2016) outlined the following technologies relevant to this paper: general-purpose machine intelligence, quantum computing, data broker PaaS, smart workspace, commercial drones, IoT platforms, machine learning, autonomous vehicles, virtual and augmented reality. Gartner further discusses two relevant key trends for 2017; smart machines and platforms. They believe improvements in computational power, Big Data[4] and neural networks will allow smart machines to dynamically adapt to new situations. Platforms will become new business model enablers by bridging humans and technology, and businesses will proactively redefine their strategies to keep an advantage.

3. Cloud Manufacturing as a Product-Service-System

Having discussed CMfg, PSS' and related technology trends, in this section a concept for introducing CMfg Systems (the product) as a new type of PSS to the market is proposed. This includes the identification and discussion of related opportunities and

---

[4] **Big Data:** Large data sets that when computationally analysed reveal behavioural patterns, trends, and associations.

challenges, including machine ownership, production decentralisation, outsourcing of major skills, economies of scale, intangible benefits, automation, logistics and distribution, privacy and cybersecurity, competitor cooperation, financial and environmental benefits, sales cannibalisation and scalability.

At the heart of the proposed concept is a machine pool management system. An intermediary company, potentially in collaboration with several OEMs, purchases manufacturing equipment and installs it in host factories around an area. The use of embedded sensors tells the intermediary when the equipment is being used, and for how long. The intermediary covers aspects of maintenance and insurance, offers remote help, and charges users for the time a service is used. The intermediary in parallel runs a website through which third parties can upload manufacturing orders. By knowing when the equipment is available, the intermediary sends the host such manufacturing orders and pays them to process them during available machine time. The intermediary organises raw material or component delivery to/from the website clients through courier transports.

Some manufacturers may perceive this as an opportunity since they would be getting access to a large network of other experienced manufacturers and accepting orders without the risk of producing unfruitful RFQs. Others might perceive the intermediary a potential threat since clients that would otherwise have contacted the manufacturer directly are now going through the intermediary and may ending up working with a competitor. Some may feel that since they do not technically own the equipment anymore, they could mistreat it, resulting in machines having to be serviced or replaced more often, which would be both financially and environmentally disadvantageous.

In general, such a CMfgPSS' may be implemented on three different levels: low, medium and high levels of machine autonomy, which is further developed and elaborated on later on in this paper. Markets are defined by choice but enabled by technology, and in order to gain the most relevant market data, the proposed CMFgPSS should be able to be implemented technically in the next ten years.

3.1 Existing Early-Stage CMfgPSS'

To date, five companies (Table 2) already provide early-stage CMfgPSS solutions relevant to the outlined concept.

Table 2 - Case studies – CMfgPSS early adopters

Company	Description
3D HUBS	A 3D printing service aiming to disrupt the manufacturing industry by putting customers in contact with 3D printer owners. They believe 3D printing has to deliver on its promises, and have created a global online platform for customers to search for an available printer close to them. 3D Hubs is challenging the idea that consumers are detached from the supply chains, where local manufacturing can be both more ecological, quicker and social. (3D Hubs n.d.)
fictiv	Fictiv's values reflect the democratisation of manufacturing. They consider themselves an innovation enabler by giving engineers access to the tools and knowledge they need, particularly during initial prototyping stages. Similarly to 3D Hubs, they have an instant quoting engine which connects designers to local manufacturers. They work with both 3D printing and CNC equipment in the network, based primarily in the San Francisco area. (Fictiv n.d.)
opendesk	A London-based company offering designers a platform to monetise their designs. Although focusing on furniture, they are pushing an open source manufacturing business model. Designers upload their files to their global platform, and customers can choose to either have the furniture manufactured by a local fabricator, or simply pay for the designs and manufacture the furniture themselves. They value craftsmanship, social development and sustainability. (OpenDesk n.d.)
MAKETIME	Similar to Fictiv but focus more on the manufacturer's point of view. They market the idea of selling (CNC) machine time easily, and believe in improving the trust between suppliers and manufacturers. They advertise being a single point of contact for US purchasers and suppliers, as well as allowing manufacturers to work at maximum capacity whilst staying on schedule. (MakeTime n.d.)
MFG.COM	The largest global contract manufacturing marketplace, connecting designers and engineers to manufacturers. They have an instant quote generator and offer services in virtually all areas of manufacturing, be it using CNC equipment or manual labour. They are more focused on medium to large volume sales by professionals, marketing their high quality network. They are committed to quality, security and price. (MFG.com n.d.)

These five companies' strategies and operations were analysed as a group to refine the initially proposed concept and identify trends. The results are summarised below:

- Target Markets:
  - Self-service platforms make it easier to attract clients
  - Manufacturers can create profiles on these platforms, which can be accessed from search engines (e.g. Google), making them more visible to external users
  - Long-lasting relationships are valued by large businesses
  - Repeatable processes (e.g. 3D printing) are easier to quote

- Order Process:
  - Customers generally order products in similar ways; part designs are uploaded to a platform and matched to a manufacturer
  - The services offered are composed of a mix of quoting algorithms that speed up and mechanise customer orders, and dedicated human experts that are sometimes included in offers to further guide customers

- Pricing Strategy:
  - Manufacturers choose their labour and material costs, although guidelines are available so they remain competitive (Cost-based-pricing based on manufacturer costs, where platforms add a commission)
  - Discounts are sometimes offered for large orders, except for 3D printing because an increase in production does not bring economies of scale
  - Platforms sometimes aggregate orders sent to manufacturers to decrease costs

- Quality:

- o Each company vets their manufacturers. Some make them produce test parts or sample, whereas others analyse their business credit to ensure stability
- o An automated test-sample analysis allows customers to join the network quickly

- Privacy and Security:
  - o All companies offer elements of cyber and legal security
  - o Several companies offer single or two-tiered Non-Disclosure Agreements (NDA's)
  - o OpenDesk offers creative commons licences to protect designers
  - o Unauthorised design re-manufacturing is challenging to enforce

- Payment and Delivery:
  - o Most companies use deposits or escrows before commencing manufacture
  - o Some companies are integrated with UPS or similar businesses to reap the benefits of global logistics
  - o Correct part packaging is often the responsibility of the manufacturer

- Additional Comments:
  - o Most companies provide additional services such as consultations, Q&A blogs, educational support materials, articles, tutorial videos, etc.
  - o There are no subscription fees for any of these platforms
  - o The platforms work strictly on commission
  - o The platforms save manufacturers money by reducing the amount of RFQs they need to send out, since every quote is a guaranteed job

    o   Designers get access to a global distribution channel with generally cheaper quotes

    o   Manufacturers are able to monetise their free capacity

    o   Although these platforms cater to the general public, they are all trying to establish a sustainable B2B business model

3.2 Identifying the Market Value

A survey across 30 manufacturing companies was conducted to identify potential market segments and what they would value most. The survey was structured in three main sections; Company context, Day-to-day challenges, and Feedback on the initially proposed pay-per-use model. The first question was used to group companies into market segments. All other answers were classified and analysed by groups to make appropriate value propositions. A wide spread of company types were found, making the survey more representative of their thoughts (Figure 1).
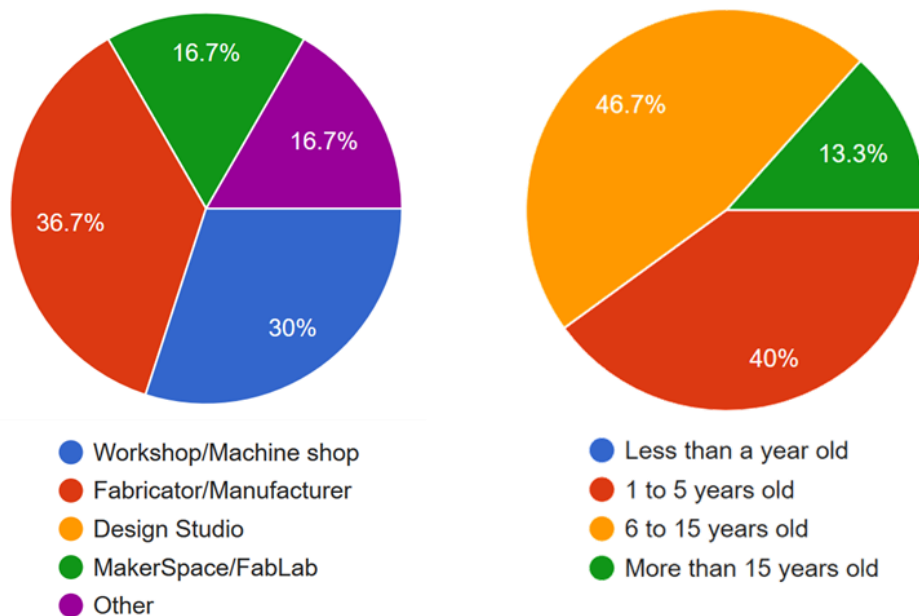
Figure 1 - Which group does your company most identify with? (left); How old is your company?

The survey's general outcomes are summarised in Table 3.

Table 3 - Survey outcomes

Survey Outcomes

Although over 90% of tasks are done using CAD/CAM technology, customers often provide poor CAD/CAM files, and lack the manufacturing knowledge to know how to improve them. This results in customers not knowing what they want, or expecting too much from manufacturers.
Most surveyed had between 2 and 5 CNC machines and between 6 and 20 hours of unused time per machine per week.
Cost and space limitations are the main reasons for not investing in new equipment.
Companies reject large orders more often than small orders
Companies sometimes reject orders due to large upfront (development) costs
Companies struggle to communicate capabilities, spare capacity and limitations to customers.
One third of company's state their equipment requires repairs once a month, often due to human error. Repairs are usually carried out by themselves, resulting in additional cost and downtime.
Manufacturers have a strong feeling of individuality. They value their quality and service over their competitors, and the personal relationships they have. They develop (irreplaceable) experience.
Manufacturers often lose clients for setting high prices, having high lead times, poor availability or the wrong equipment.
Manufacturers would appreciate a third party dealing with cleaning, material handling, stock taking and quote production.
Approximately 60% of RFQs actually become orders, corroborating MakeTime's business model.
Although currently not ideal for everyone, around 2/3 of the surveyed would consider using this model, with 1/3 of them wanting it to be proven in operation before using it.

3.3 CMfgPSS Value Proposition Models

Strategyzer developed a tool to map customer segments to proposed offerings
(Osterwalder, Pigneur and Bernarda, et al. 2014), called the "Value Proposition
Canvas". The right hand side represents the customer and its requirements, and shown
on the left are the solutions, as driven by the customer. It maps out the benefits (gains)
that clients can get from a service offering (which they might not get otherwise) and the
risks (pains) clients are mitigating by using the services. By analysing the core of the
customer needs, the tool illustrates how the proposed services are beneficial to the
clients. The information in Figure 2 was derived from the results of the survey.

Gains
- Access to additional manufacturing capabilities
- Remain as a self-service business model
- Keep in-house experience with minimal part-time staff
- Maintain warm customer relationships
- Manufacturer's high quality and reputation reflected
- Improved order predictable and lead times

Customer Job(s)
- 3D Printing
- Cleaning up
- CNC Laser Cutting
- CNC Milling
- Offering advice or tutorials
- Preparing CAD/CAM files
- Preparing RFQ's
- Stock taking
- Vinyl Cutting

Pains
- 1-20 hrs unused machine time per week
- Clients unaware of manufacturer's capabilities
- Machine repairs taking multiple days or weeks
- Machine repairs taking multiple days or weeks
- Limitations for purchasing new equipment
- Discussions or RFQ's that don't lead to sales
- Machine repairs taking multiple days or weeks
- Poor production planning
- Customers producing poor files or having hidden requirements

Gain Creators
- Selling unused machine time
- Access to network of pay-per-use equipment and like-minded people
- Customer feedback & video communication through platform
- Demand levelling & elastic scalability
- Integration with transportation company (e.g. FedEx or UPS)
- Work exclusively on CAM files
- Raw material purchased as a cooperative for lower prices

Products & Services
- Machine pay-per use model
- Co-op raw material purchasing
- Customer guidance (e.g. blogs)
- Digital platform for manufacturer-client communication
- Integration with transportation companies
- Scalability with networked equipment
- Machine repair service communication

Pain Relievers
- Sending job orders instead of RFQ's
- Subsidised machines installation price
- Machine pay-per-use model and selling unused machine time
- Manufacturer profiles with detailed descriptions of works done
- Production and resource levelling through network-wide balancing
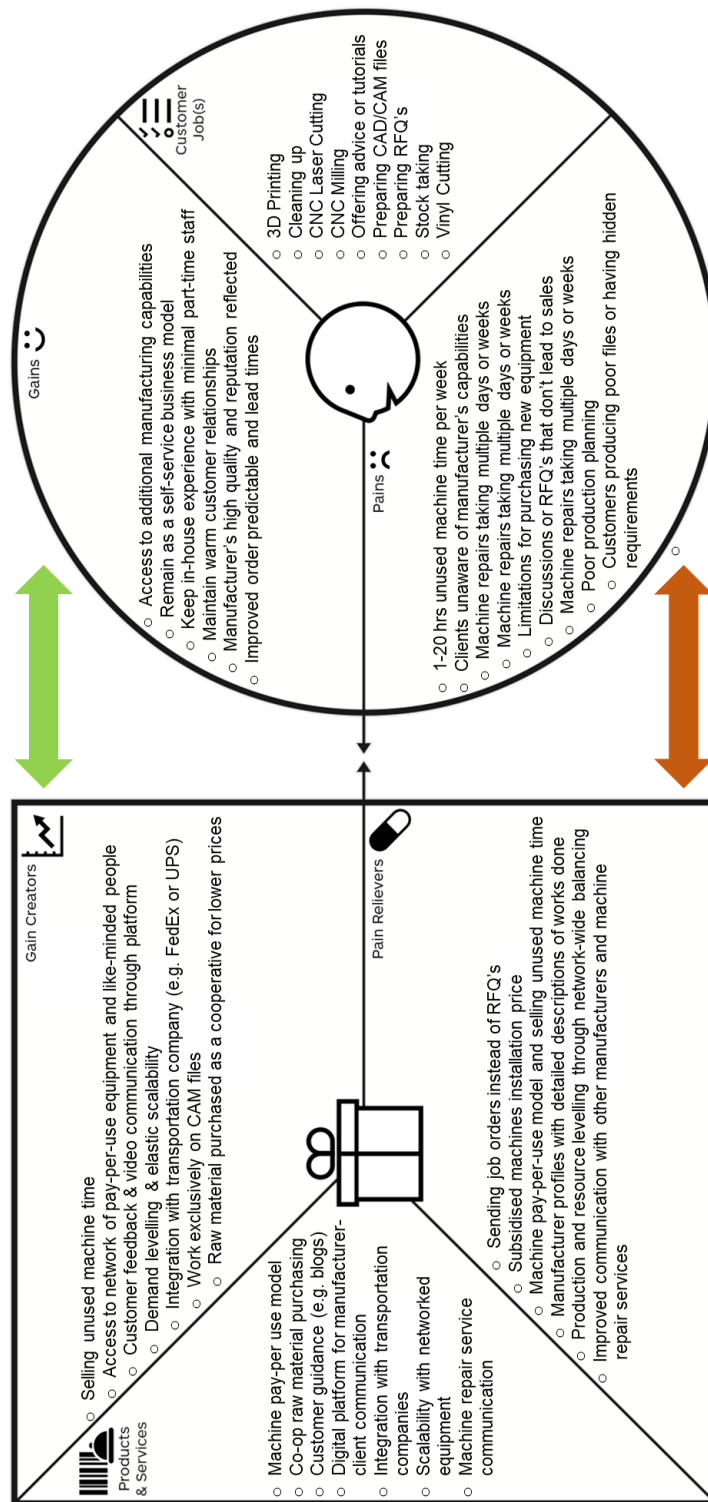- Improved communication with other manufacturers and machine repair services

Figure 2 - Target market value proposition canvas

3.4 Business Requirements

As alluded to before, the proposed CMfgPSS business model can be implemented on three different levels to account for ongoing developments in technology. Manufacturing is currently operating with a relatively low level of autonomy, relying

heavily on human interaction. At a medium level, only partial human interaction would be necessary, with machines influencing many decisions. At the highest level, there would be virtually no human interaction.

Given that the proposed CMfgPSS must have market relevance whilst dealing with the uncertainty of future technologies, the business model targets a CMfgPSS with low autonomy levels where the core idea is to sell manufacturing capabilities, not machines. The following guidelines have been created to form a business model that is applicable to the manufacturing industry at large rather than a proprietary business plan.

Value Streams

Equity and Game theory as described by Wu et al. (Wu, Greer, et al. 2013) influenced the equipment pay-per-use model. Equity theory describes how individuals in a group may react to disproportionately distributed results, emphasising that fair compensation in CMfgPSS' is essential to maintain collaboration amongst the network. It develops how satisfaction is highly driven by value appropriation, with individuals trying to maximise their profits. Inequitable relationships result in individuals experiencing distress, although the open and frequent exchange of information can ease tensions between competitors. Finally, collaborators will compare their rewards with those of others. Game theory describes how rational individuals make decisions in mutually interdependent roles. Here, formal agreements will be used to ensure a cooperative environment is enforced.

With this model, a CMfgPSS provides manufacturers with equipment and added services. The host books the equipment for a minimum amount of time (e.g. 6 months) after paying for the installation fees, and then renews the contract on a rolling basis (e.g. 3 months). On every renewal the host schedules an estimate of how many hours per week they expect to use the equipment. Hosts then fix their platform-work hourly rate

and raw material costs with the CMfgPSS. Since the host is saving money by using the platform and not preparing RFQs (of which only 60% actually become orders according to the survey), the platform-work rates can be lower than what they would normally charges clients. If a user sends a part order through the platform, it would automatically quote a price. The host rate (assume 70%) and CMfgPSS commission (assume 5%-25%) would add up to less than what the customer would have originally paid by contacting the host directly (100%). Host earnings would increase overall because they would not be spending time preparing RFQs, and the platform would have gained a commission on the transaction (Figure 3). Much like UBER[5] is able to manipulate their prices according to demand, a CMfgPSS varies its prices to stimulate or level production. The platform could also suggest manufacturing prices to hosts to make their offers more competitive.
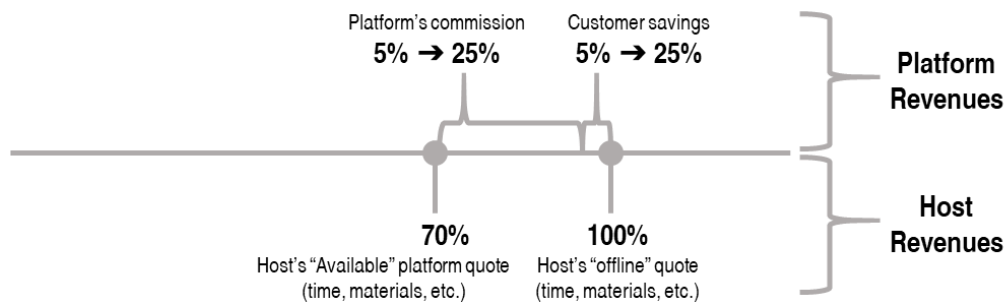
Figure 3 - Example platform job quoting approach

After a one-time machine installation fee, "Usage" is charged per unit time (e.g. per 15 minutes). The price depends on how much machine time the host has pre-scheduled for themselves, based on their estimate of how many hours per week they expect to use their equipment. For explanatory purposes (Figure 4), it will be assumed that a machine host pays 100% for unscheduled/priority equipment usage, and 80% for pre-scheduled equipment usage. If the host chooses not to use the equipment, they

---

[5] **UBER:** A popular on-demand sharing economy transportation service.

would have two choices: set the machine to "Do-Not-Disturb" or "Available". Hosts that set machines to Do-Not-Disturb mode will not receive any orders, but will be charged a low depreciation fee (e.g. 10% of usage price), although the surveyed companies seemed to prefer not to be charged anything (Appendix 2). If the machine is set to Available the host will not be charged anything, but may receive an order from the platform, paying only 60% for working for the platform. The idea is to incentivise manufacturers to take all their orders from the platform, so system-wide supply can be predicted and levelled. Hosts can choose to accept or reject incoming orders from the platform. The platform will pay the manufacturer for any accepted orders, as depicted in Figure 3. Manufacturers that reject orders without a valid reason will suffer penalties such as having to pay for "Available" machine time, paying an increasing amount for "Do-Not-Disturb" or "Usage" time, being sent less popular orders, or ultimately being removed from the network, returning the equipment and paying an early contract termination fee. Hosts are also charged 110% for hiring another network machine to scale up production. This is higher than what they would pay to use their own equipment, but lower than what an external customer pays to hire the service.
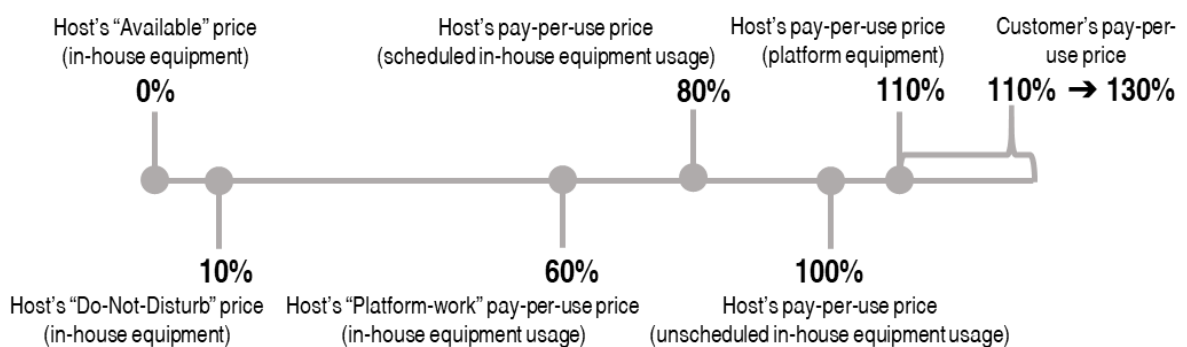

Figure 4 - Example equipment usage prices

By converting a host's capital expenditure to operational expenditure, a CMfgPSS enables perpetuating revenue streams. In any case, the host always has priority use over their equipment.

The model relies on either OEMs developing equipment with smart sensors, or retrofitting their legacy systems with this technology. The large amounts of Big Data collected from the equipment could be sold back to the OEM's so they could analyse equipment performance and improve future models. This, however, might raise privacy concerns from manufacturers. Insurance companies may also be interested in the data when assessing damage claims.

Academic research may benefit from such platforms and data as well. For example, improving manufacturing techniques often requires a large set of experimental results, which may take long to collect. With this platform, researchers could purchase time on multiple machines, and simultaneously manufacture components in slightly different ways. Machine sensors would record their parameters and results, which would be fed back to the researcher for analysis (e.g. energy consumption with varying cutting speeds), much like they would if they were running an experiment in their laboratories. Having such a large manufacturing network would reduce total experimental time by several orders of magnitude.

Shared Value, Shared Benefits

The proposed sharing economy is anticipated to provide significant benefits to machine hosts, OEMs and users (e.g. enthusiasts, industrial companies, design studios, etc.).

With a large network of manufacturers, the platform facilitates the purchasing of raw materials and tools in bulk, like a cooperative. Bringing economies of scale to SMEs would bring costs down and make their prices more competitive.

The survey results suggest that downtime due to machine breakdown is often in the order of days or weeks. By allowing hosts access to additional equipment, a distributed manufacturing network would potentially mitigate downtime. It may also mitigate employee sickness by ensuring someone on the network is always available,

whilst allowing hosts to rapidly scale up demand and access a wider variety of equipment. The ideal system makes increasing machine usage on a CMfg as easy for users as increased data storage on cloud computing currently (e.g. Dropbox).

Hosts see requests made through the platform as job orders instead of RFQs. The order goes to anyone on the network, but since the profits received per order would be larger (due to not spending time preparing RFQs) manufacturers would be working less for the same revenues. This allows the platform to implement system-wide work balancing without disappointing hosts.

Communication between hosts, the platform and OEMs on design improvements would ensure next-generation machines are suitable for CMfg. Environmental benefits include machine sharing (less overall number of machines in the network) and more efficient next-generation equipment.

Privacy & Security

Most of today's open-source design/manufacturing services rely on good will from the users. For commercial CMfgPSS to be successful, legally binding regulations are to be established. All contracts must be legally binding, with manufacturers being vouched for financial sustainability as well as manufacturing skills. Customer/platform/host NDA's will need to exist. Users will choose whether they want to sign a baseline NDA, propose a personalised one or not sign one at all. To stop competing producers manufacturing sensitive parts for each other (e.g. Airbus manufacturing Boeing components), users will use a mixture of pre-approved suppliers and two-tiered NDA's.

Cloud-controlled machine-to-machine communication without human intervention will eventually pave the way for a future "Alibaba of design and manufacture" – for lack of a better term. Hosts will never need to have digital access to the files, since the machine would directly access them from the cloud. With advances

in technology, if the designer did not want the host to see the part or processes, the machine windows could black out during manufacturing. The machine then autonomously places the part in a tamper proof bag, such that the host would only input raw material and get a sealed package. In any case, the host is working for the customer, so all production is owned by the customer, even if the customer is another host splitting its own production.

Support

It is recommended that CMfgPSS providers partner with several OEMs and MROs (Maintenance, Repair and Operations) companies. This ensures hosts have access to remote specialists (ideally) on demand and receive preventive maintenance. Partners are required to use the platform to ensure brand and quality consistency. A given host has priority over another host's available time until their machine is repaired.

Following feedback from the survey, the platform should offer some form of articles, blogs and/or tutorial videos targeted at customers. These educate clients on basic CAD/CAM, design for manufacturability and equipment limitations to ensure job orders are made correctly. If hosts deem a customer is not familiar with certain processes, they can recommend them to complete the relevant tutorials and revise their designs. If several hosts recommend the same tutorials to a client, the client may not be allowed to make further orders until they have completed them.

Logistics

Raw material and manufactured part transportation should be outsourced to a large company with global reach (e.g. UPS, DHL, etc.), ensuring customers benefit from parcel tracking and same day delivery.

Since hosts would treat platform orders in the same way they treat traditional orders, they will store the finished goods in their facilities. Delivery companies often offer free packing and labels to their members (UPS n.d.). The concept of CMfgPSS' renting areas of a host's factory for finished goods storage was explored, but not further developed.

Target Markets

There are three target market categories; machine hosts, mass market (professional or not) and OEMs.

Four SME machine host groups were identified (workshops, maker spaces, fabricators and design studios), however additional groups may be underutilising their equipment, including hobbyists/enthusiasts, universities or larger companies. From the survey, there were no consistent profiles for accepting/rejecting the proposed concept. The surveyed replied on whether they felt the model would work, rather than if it was appropriate for their specific industry. Having said this, the CMfgPSS is currently not suitable for very high tolerance industries (aerospace, automotive, etc.) because process consistency across manufacturers is challenging to replicate.

Mass market users (external to the platform) interested in this offering are likely to initially make one-off orders until they have gained sufficient confident in the service. Anyone wanting a product manufactured (e.g. hobbyists, large manufacturers, etc.) would be targeted, although it will be challenging to capture customers with large order volumes and complicated manufacturing processes early on, since these orders will inherently be split across hosts and quality may be an issue until technology has developed.

OEMs should be key partners, since they will be developing some of the technologies. The CMfgPSS could work directly with a company by becoming

exclusive to it, much like Car2Go operates with Mercedes-Benz. Unfortunately this model requires a high number of machines connected to the network, and unlike Car2Go users, hosts tend to be more selective of the equipment they use. It is in the interest of the CMfgPSS to maximise geographic coverage as early as possible, and for this it will have to be connected to all equipment brands.

Costs

The company that develops this business model may encounter some of the costs identified below.

Assuming low level autonomy machines are developed, the CMfgPSS will purchase equipment and install it in manufacturers' facilities. The CMfgPSS would therefore finance the host's equipment, but the higher usage per machine and pay-per-use profit margins should offer CMfgPSS' a good return on investment.

Due to the higher equipment usage, they may require repair more often, although this will be mitigated by partnering with MROs. Whereas the host would have traditionally absorbed the cost of obsolescence, it will now be factored into the pay-per-use payments. CMfgPSS' talk to OEMs to ensure new equipment is modular and can be upgraded or repurposed.

Finally, there will be costs involved in developing and running the platform and software, as well as marketing and administration. These could be estimated by comparing the project to historical data from other projects of similar technical challenges and scale.

3.5 Technology Requirements

The described CMfgPSS will need several technologies to develop further before it may reach its full potential. McKinsey (McKinsey & Company 2015) estimates that I4.0 has

the potential to reduce machine downtime by 30-50%, inventory holding costs by 20-50%, maintenance costs by 10-50%, with increased forecasting accuracies of 85%+. The technologies enabling this CMfgPSS are aligned to the system's levels of autonomy. Table 4 illustrates the technology developments required for each level of autonomy.

Table 4 - Expected technology developments for each autonomy level and year

Technical Area	Low (2017-2025)	Medium (2025-2040)	High (2040+)
Machine Optimisation	Universal machine language Upgrading legacy machines' control systems	Machine Big Data collection & analysis Remote monitoring and control	Artificial Intelligence
Part Quality		Autonomous machine decision making Remote monitoring and control	Mid-manufacturing corrections
Resource Management		IOT-driven autonomous stock control	Artificial intelligence On-site tool 3D printing
Equipment Maintenance		Remote monitoring and control	Augmented reality
Deliveries		Driverless vehicles	Autonomous drones
Platform		Cybersecurity improvements Machine Big Data collection & analysis	Artificial Intelligence Quantum Computing

Machine Optimisation

Interoperability is a key limitation with current CNC equipment. The degree to which equipment usage is maximised will be highly dependent on their ability to communicate with a platform and each other (Mourad, Nassehi and Schaefer 2016). When manufacturers prepare a CAM file they tailors it to the machine being used, since different brands will use slightly different programming codes. Although G&M-Codes/StepNC are implemented for milling machines, a single programming language flexible enough to be used across all equipment (milling, laser cutting, 3D printing, etc.) still needs to be created (Mourad, Nassehi and Newman, et al. 2017). This language would then enable a platform to interrogate machines and automate production, making designs directly transferrable from machine to machine. For example, it might allow a platform to suggest the host pools a 3D printer's bed with another manufacturer (i.e. if there is free space on the machine, another part is added onto the print, so multiple

components are printed at the same time). This will require adapting legacy manufacturing control systems, as well as designing new equipment. In fact, according to a McKinsey report (McKinsey & Company 2015), the 4th industrial revolution will probably only need partial replacement of equipment (40-50%), unlike the 3rd where replacement was as high as 80%.

A greater level of autonomy can be achieved when additional sensors on equipment are recording real-time usage data (Big Data) which the platform can interpret. These will enable smart monitoring (e.g. predictive maintenance, energy consumption, etc.) and decide at factory level whether, for example, a particular machine would require less maintenance in the long run by producing one component over another. It will also allow remote monitoring and control, which is the first step to manufacturing self-reorganisation, and will require machines to communicate with factory planning software.

At the highest level of production autonomy, modular equipment will communicate with each other (between factories through the internet), and make these decisions on their own, optimising usage at a network level. Also, if a 6-axis mill is working at full capacity, the system could recognise this and spread the tasks onto a vertical and a horizontal mill or a 3D printer (if appropriate), using different manufacturing processes but reaching the same solution whilst alleviating the load on the system. Getting this aspect right is critical, and may require a level of artificial intelligence. Components often require processing in multiple machines, so they will need to coordinate with each other appropriately and prioritise one factor over another whilst factoring in logistics.

Part Quality

Part repeatability across equipment is a challenging area for high tolerance components.

Manufacturing equipment will need smart sensors to accurately measure the environment (temperature, humidity, etc.) as well as itself (tool accelerations, wear, etc.) to evaluate the effect of, for example, raw material quality or thermal expansion. At the lowest level of autonomy an operator would edit CAM files based on personal experience to account for changes between geographical locations. Medium level equipment would make CAM suggestions to the manufacturer from its readings of the environment. At the highest level of autonomy, a CAD file would be created at a central hub and sent to machines around the world. These machines would measure their environment, compare it to a desired baseline and then autonomously create and edit CAM files to ensure the final product has the same tolerances (Figure 5). Another way to overcome environmental issues is to manufacture each part in small environmental chambers with the same conditions, but this seems unfeasible.
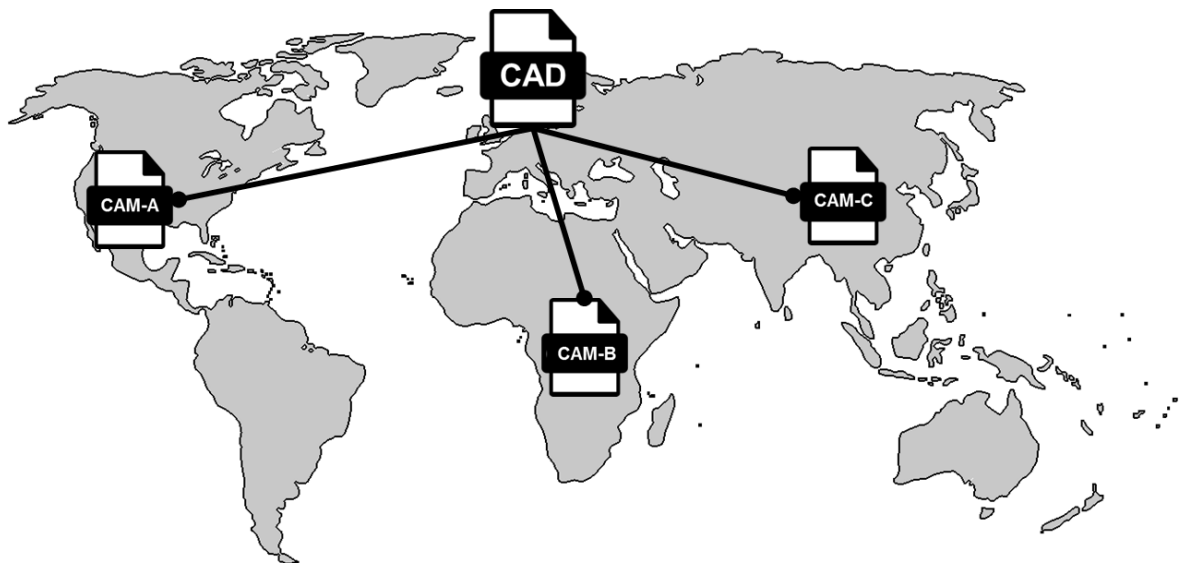
Figure 5 - Conceptualised machine CAM design

In contrast with this proactive approach, if systems are to become autonomous there will have to be reactive quality control sensors in the equipment to override the CAM files. At an early level this could be done through remote monitoring and control from a hub, but at a higher level of autonomy the machine would correct the part on its own. For example, if the overhang on a 3D printed component is not as expected, the

part would be scanned mid process and more material would be added as required. This would ensure every component manufactured was at the desired tolerance, helping to reach targets (e.g. 6-Sigma).

Resource Management

A true PSS in this context should provide everything needed to run the equipment, with users only worrying about how much time they need on it. At a low level of autonomy the manufacturer would contact the platform to request more material in order to benefit from economies of scale discounts. At a medium level the facility would have IoT sensors (e.g. RFID, micro scales, light gates, etc.) to allow the platform to measure raw material stock levels in each facility in the network. The platform could therefore manage a Kanban[6] system (just-in-time production) across all facilities. At the highest level, Big Data collected from these facilities would be interpreted and used for sales forecasting. Historical-based forecasting through pattern recognition could provide companies with predictive restocking such that they never need to reject orders, because the system would have anticipated them.

Another aspect to manufacturing is the tooling used. Although at early stages tool usage could be monitored similarly to raw material, in an ideal scenario, if a tool broke down unexpectedly or a specialist tool was needed, it might be 3D printed in the factory on demand. This, however, would require advancements in metal 3D printing quality and repeatability.

---

[6] **Kanban:** A manufacturing model where material supply is regulated through instruction cards sent along a production line.

Equipment Maintenance

At the lowest level, maintenance could be sped up by integrating part delivery with a transport company such as UPS. At the medium level the platform would analyse equipment sensors' Big Data to predict when parts would break down and change them in advance. At a high technological level machines could come with a device similar to "Google Glasses" (i.e. glasses with a camera on them which accommodate augmented reality). If a problem occurred on the machine, the operator would put on the glasses and be connected through audio/video to the MRO. Remote experts could guide the user through basic maintenance without needing to be dispatched, reducing the machine's downtime.

Deliveries

Initially deliveries would be outsourced to a transport company such as UPS, due to their global reach and economies of scale benefits. As technology develops, these transportation companies may adopt driverless truck technology, improving delivery times and further decreasing costs by reducing labour. At the highest level of autonomy, drones could deliver components as and when they are produced. Using RFID tags, a drone could fly into a factory, collect a package and deliver it. In addition, since drones can travel in straight lines between customers they could further reduce delivery times, especially in rural or geographically-close areas (assuming range, speed and battery life are improved).

Platform

As discussed, apart from supporting the website, the platform would need to have the computational power to process the network's Big Data very quickly.

With respect to a corresponding website, there would be several requirements, including offering video conferencing capabilities (e.g. Skype, WebEx, etc.) and CAD/CAM integration to allow for real time collaboration. The website would also allow companies to create individual profile pages where their equipment can de virtualised (digitally represented in terms of characteristics) in detail. It would provide quote tracking and allow buyers/suppliers to rate themselves (e.g. 5 star system).

The platform provides other basic services such as automatically fixing geometric mistakes in files, instant quotes based on historical and local data, and ensuring a high level of cybersecurity. The cybersecurity issue is of upmost importance to provide users with confidence and protection.

These technical requirements are already available and could be covered by renting server space on cloud management providers (e.g. Google Cloud). The next level of technical difficulty would come with increasing the quoting engine's speed and reliability, and the system's overall cybersecurity. The highest level of improvements would come from artificial intelligence autonomously monitoring machines in real time. Advances in server technology or quantum computing may accelerate this process.

3.6 Business Model Canvas

CMfg Systems, in future, may become more than just a linear development of traditional Manufacturing Systems. They may become a new type of PSS, as developed in the following business model. This evolution is analogous to what the IT sector has experienced multiple times, such as the change from selling hard disk drives to selling cloud storage space as well as providing additional services such as back-ups and cross-user collaboration capabilities. The proposed business model servitises a CMfg system following the PSS principles discussed in the literature review, covering the following job categories:

- Functional (core to the customers' business)

- Supporting (support the main functions)

- Social (improve how customers are perceived by others)

- Emotional (improve how customers feel about themselves)

Strategyzer's "Business Model Canvas" (Osterwalder et al. 2010), a strategic management tool, was used to design, describe and challenge the business model. Figure 6 illustrates how value propositions fit within the canvas. It is a concise way of mapping an entire business on one page through 9 building blocks:

(1) Customer Segments: people or organisations for whom the CMfgPSS is creating value

(2) Value Propositions: specific services that create value for CMfgPSS customers

(3) Channels: networks for interacting and delivering value

(4) Customer relationships: the type of relationships the CMfgPSS is establishing with customers

(5) Revenue streams: pricing mechanisms to capture value

(6) Key resources: the CMfgPSS' indispensable assets

(7) Key activities: areas where the CMfgPSS needs to perform well

(8) Key partners: partners which can help leverage the CMfgPSS

(9) Cost structure: the costs incurred in operating the CMfgPSS

The proposed business model (Figure 7) acts as a multi-sided market, where there are three main customer segments; machine hosts, mass market and researchers. Although the paper has focused on developing the machine hosts' needs, all three customers are needed for the model to work. The proposed model focuses on low

autonomy levels, but as technology develops and the CMfgPSS begins a vertical

integration, machine hosts will become less crucial.

Figure 6 - Relation between value proposition and business model canvas (Osterwalder, Pigneur and Bernarda, et al. 2014)

Business Model Canvas

Key Partners
- Insurance companies
- Machine repair and maintenance companies
- Raw material providers
- Machine manufacturers (OEM)
- Software providers (e.g. Autodesk 360)
- Global reach transportation companies (e.g. UPS, FedEx, etc.)

Key Activities
- Collect/analyse machine use Big Data
- Equipment predictive maintenance
- Machine virtualisation
- Accurate host capability descriptions
- Network bulk raw material purchasing
- Production and demand levelling
- Q&A blogs, industry trend events, design for manufacturing tutorials, etc.
- Platform management
- Platform promotion
- Instant manufacturing quote generation
- Cybersecurity

Key Resources
- Platform and website
- Big Data processing algorithms
- Server power
- Diverse host network
- Manufacturing equipment
- Machine-to-machine communication technology

Value Propositions
- Access to shared knowledge
- Access to informed customers
- Less RFQ preparation/order rejection
- Access to varied equipment
- Machine/operator downtime mitigation
- Rapid elastic scalability
- Quick global delivery capabilities
- Single point-of-contact
- Reduced raw material costs

- Access to shared knowledge
- Less rejected orders
- Access to varied equipment
- Access to local/global manufacturers
- High delivery speeds
- High quality products
- Single point-of-contact

- Access to shared knowledge
- Access to manufacturing data
- Access to varied equipment
- Instantaneous global reach
- Faster experimental results

Customer Relationships
- Personal assistance
- Optional NDA's
- Online like-minded community
- Automated host-client matchmaking

- Optional NDA's
- Online community & host rating
- Automated self-service part upload and machine host matchmaking

- Personal assistance
- Optional NDA's

Channels
- Platform
- Personal sales force
- Online blogs

Customer Segments
Machine Hosts:
- Workshops/Machine Shops
- SME Fabricators/Manufacturers
- MakerSpaces/FabLabs
- Design Studios
- Universities
- Large Manufacturers

Mass Market:
- Individuals/Enthusiasts
- Start-Up's/Prototypes
- Students (schools and universities)
- Small and medium volume orders from companies or other hosts
- Industrial manufacturers

Researchers:
- Large manufacturers improving processes
- Academics researching manufacturing techniques
- Machine manufacturers improving equipment (R&D Departments)
- Insurance companies assessing human error in damage claims

Cost Structure
- Equipment investments and part replacements
- Platform running, development and maintenance
- Software technology development
  - Instant order costing algorithm
  - Big Data analysis and predictive maintenance algorithms
  - Network communication and security
- Subscriptions to insurance, package delivery, software usage
- Potential machine host technical and financial vetting

Revenue Streams
- Machine installation fees
- Pay-Per-Use rolling contract

- Unused machine time
- Platform transaction commissions

- Machine usage Big Data
- Access to a global pool of varied equipment

→ Machine Hosts → Mass Market → Researchers

Figure 7 - Proposed CMfgPSS business model canvas

4. The Road to Success

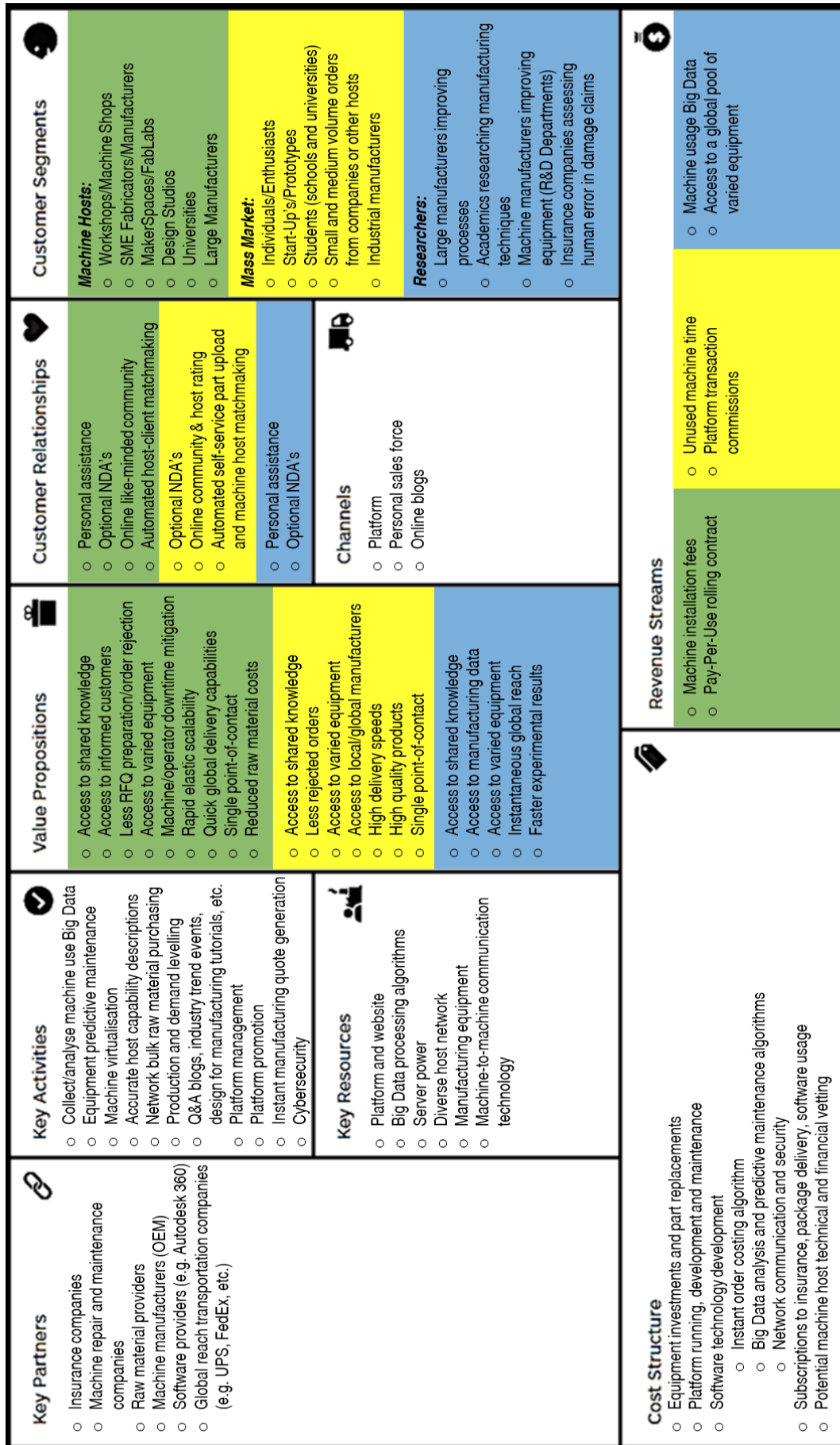The proposed low autonomy level business is anticipated to be implemented on a larger scale within the next 5 years, where the themes outlined below must be targeted.

4.1 Deployment Strategy

The model depends on geographical economies of scale to ensure both raw materials and finished products are delivered quickly. Initially, a collection of geographically close manufacturers should be targeted, which together form a hub. The first target hub should be in a heavily manufacturing dependent area (a large target market). As the hubs grow they will slowly merge with each other, forming a country wide and eventually global network. The emphasis is in capturing a large range of manufacturing technologies. This step-by-step deployment strategy will ensure coordination and analysis of the first "pilot" areas, but may result in a slow return on investment.

4.2 Capturing the Right Audience

It is essential to target manufacturers from multiple industries to ensure machines are available throughout the year. If only one industry was targeted, and that industry was always busy (high season from January to March), the platform would not have enough spare capacity to supply the external demand. In contrast, during low season there would be a capacity surplus.

It is important to distinguish the target market transition in CMfgPSS'. Manufacturers (hosts) will initially be targeted, but as technologies develop, CMfgPSS' will slowly absorb them as they integrate vertically, due to high quality process automation. The platform will then target designers more than manufacturers. A similar example is taking place in the automotive industry with Car2Go and self-driving

vehicles. Where leasing company's traditionally targeted taxi companies, now that taxi drivers are slowly being replaced, the companies target consumers directly.

Different hosts will be interested in different areas of the model proposition. Some may only want "smart" preventive maintenance, others access to better equipment, and others will want it all. However, cherry-picking parts of the proposition will not necessarily make it cheaper for hosts, because the model works best as a whole (Martinez, et al. 2010). The CMfgPSS will have to adapt to each customer's strategy, whilst trying to influence its company culture to align it with the model. Companies in countries such as USA, which already use Maketime or MFG.com, may be less reluctant to change their business models, and could be targeted first. Having said this, with no major rivals in Europe, it is up to the CMfgPSS to balance which country to target.

To capture these markets the CMfgPSS will need to manage expectations by closing the gap between what they think the customers expect and what they actually expect, delivering results as promised.

4.3 Financial Planning

It is essential for the CMfgPSS to accurately cost the platform and charge accordingly, or it could run into cash flow difficulties. This is partially mitigated by charging for installation costs and quick rates of return, but still needs to be addressed. A company that decides to become this CMfgPSS should ideally already have solid revenue sources to ensure it can sustain the first few years of implementation.

4.4 Change Management

A lot of research has been conducted on change management, which could prove useful when deploying a CMfgPSS. Fauvet's theory of socio-dynamics (d'Herbemont, et al.

2007) can be used to anticipate a player's role in the face of change. This change management tool measures a person by their synergy[7] and antagonism[8], classifying them into manageable groups. Each group provides distinct opportunities and threats to the project, and can be used to an advantage by encouraging their support or taking in their feedback. Allocating stakeholders to their representative groups could therefore allow their moves to be predicted.

5. Critical Analysis and Discussion

In this section, a critical analysis of the proposed Cloud Manufacturing Product-Service-System is provided. To aid the process, a number of well-established analysis tools are employed to assess both the proposed CMfgPSS model and its external business environment.

5.1 Porter's Five Forces

A Porter's five forces analysis reflects the level of competition a strategy will encounter in an industry. Determining the competitive intensity reveals a proposal's attractiveness (Figure 8).

---

[7] **Synergy:** The energy a player develops (or can be developed) to support a project.

[8] **Antagonism:** The energy a player develops against a project.
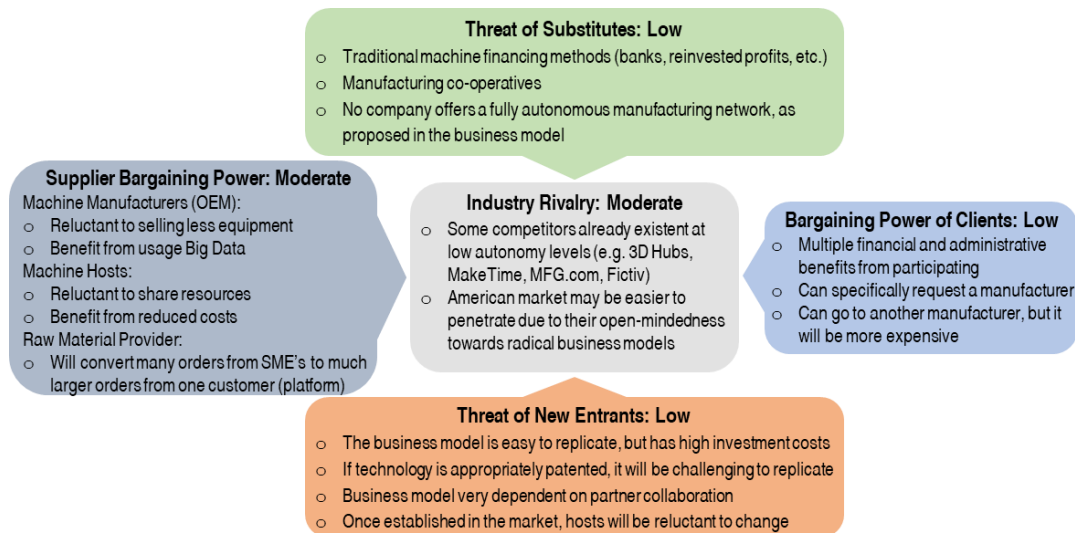
Figure 8 - CMfgPSS Porter's five forces analysis

5.2 PESTLE

PESTLE (Political, Economic, Social, Technological, Legal and Environmental) assesses macro-environmental factors, reflecting on the model's effect on society and vice-versa (Figure 9).
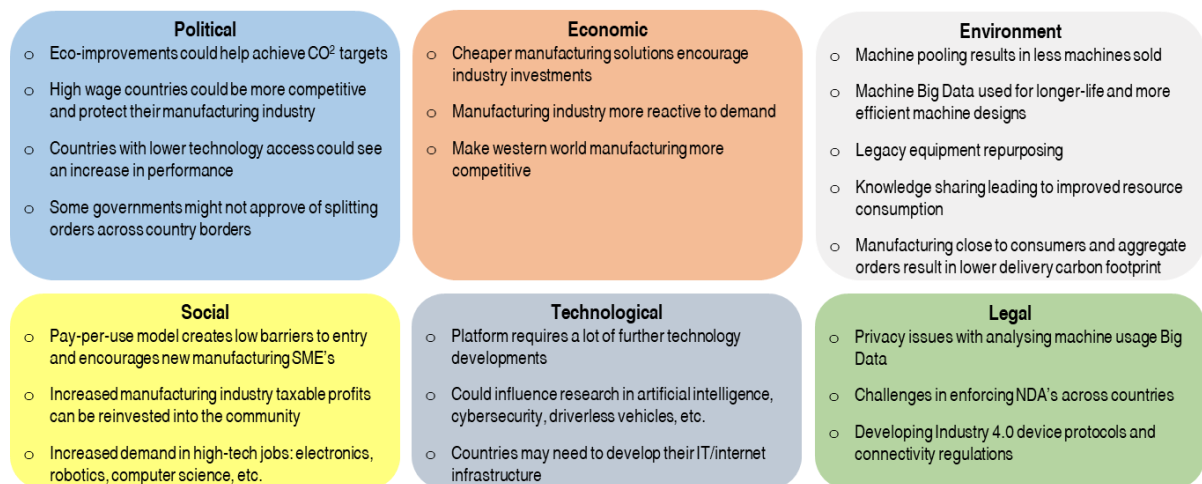

Figure 9 - CMfgPSS PESTLE analysis

5.3 SWOT

SWOT (Strengths, Weaknesses, Opportunities and Threats) is useful in deciding whether a proposal is attainable by assessing external and internal factors (Figure 10).

Internal

Strengths
- Equitable pay-per-use rates prioritise network members
- Machine host community ratings reflected through poor-performance penalties
- Platform and business model scalable to technology improvements
- Pay-per-use nature ensures constant cash flow
- Host network manufactures for the platform
- Provides legal coverage through two-tier NDA's
- High technological barriers to entry by competitors
- Multiple value streams, monetising more areas of the products' lifecycles through contracts

Weaknesses
- Large number of users required to reach critical mass
- Traditional/paper-based manufacturers not targeted
- Not ideal for companies with an established supply chain
- Pay-per-use results in slow return on investments
- High equipment and technology development costs from the beginning, leading to cash flow problems
- High reliance on manufacturers to maintain their quality standards
- Different levels of knowledge and skill across the network

Positive — **Negative**

Opportunities
- Cater for multi-process manufacturing, or distributed product assembly
- Offer cleaning services (requested in the survey)
- Developing the artisanal manufacturing market
- Scalable nature could allow the platform to absorb most (if not all) the manufacturing industry
- Become directly involved in machine design
- Expand into multiple countries because machine virtualisation overcomes language problems

Threats
- High dependence on technology and future developments
- Data privacy and cybersecurity issues
- Too many customers relying and not enough hosts
- High dependence on key partners, who may fear improved equipment may cannibalise spare parts market
- Heavy reliance on Big-Data market trend predictions
- Culture clashes due to machine host greed
- Hosts sabotaging their competitors' orders
- Machine host/operator reluctance to share usage data to prevent autonomous manufacturing system development
- Poor machine host behavior reflected on the platform
- Low sense of machine ownership results in equipment mistreatment or hosts abusing the model

External

Figure 10 - CMfgPSS SWOT analysis

5.4 Model Validation

The proposed business model is the result of primary, secondary research and concept iterations. It is a new development on current CMfg concepts outlined in the literature review based on PSS theories. Business model validation is a very complex area, and the best way of assessing its success is to actually create a CMfgPSS. Since the proposed concept may take a few years to fully propagate into industry, a complete validation is not possible at this point in time.

However, the core concept was shared with a number of manufacturers who ensured the authors of its relevance (feedback in Table 5). The survey targeted potential machine hosts because they are at the core of this proposal; without them there is no machine network. Although successful, the survey could be improved upon. The companies surveyed were taken from community-based manufacturing directories (OpenDesk n.d.) (FabHub n.d.) and therefore may have been more open to accepting this idea. In addition, only small and medium sized manufacturers were contacted, excluding large manufacturers and other institutions such as universities.

Table 5 - Survey model feedback

Positive Feedback	Negative Feedback
Access to better machinery	Inconsistent quality
Lower overall costs	Not apt for specialist markets
Levelled workload	Low number of well-trained hosts
Ability to take in larger orders	Reluctance to change
Increased capacity	Machine host greed
Lower capital requirements	Challenges in sharing fractions of orders
Additional profits	Collaborating with unknown people
Accepting less risks	Confidentiality issues
Improved business network	Difficulty in predicting machine usage
Freeing factory space	Company culture clash
Less overtime	Companies wanting machine ownership

The feedback was used to develop the final business model, but should be taken with care, considering stakeholder management techniques.

Although obstacles are to be expected in terms of the model's initial acceptance, the positive survey feedback presents it as a sound proposal. The model is, however, at initial stages and will need further development.

6. Conclusions

This paper explored the research question "Could Cloud Manufacturing be offered as a new type of Product-Service-System with an associated underlying new business model?" The CMfgPSS business model proposed aims to become a baseline from which future and refined models may develop. The intermediary platform targets both

potential machine hosts and the mass market, whilst capturing additional revenue from academic and industrial research. The machine pay-per-use system helps machine hosts become more competitive by reducing investment costs and enabling instant manufacturing scalability. By making use of spare capacity the platform can bring down costs for the mass market, whilst creating new sources of revenues for both machine hosts and the platform. The paper has focused on developing the machine hosts' basic needs, but all stakeholders need to be further analysed before the proposal is implemented.

The CMfgPSS fits between a "Use" and a "Result" oriented PSS. To be successful, the platform should maximise geographic coverage as early as possible, and will therefore need to be compatible with multiple equipment brands. Understanding user needs is paramount to a successful proposal. Whilst the model will adapt to each customer's strategy, it should also try to align the hosts' company culture to the model. They will need to be persuaded that it is not always necessary to own of a physical machine, and will have to trust that the platform can deliver the manufacturing quality it promises. Communication between hosts, the platform and OEMs on design improvements would ensure next-generation machines are more suitable for CMfg. This could lead to environmental benefits by having a smaller network of more efficiently used next-generation equipment. As technology develops CMfgPSS' may slowly integrate vertically and replace manufacturers by completely autonomous equipment.

Recent technology developments have challenged traditional business models, and adapting these is key to a sustainable competitive advantage. The business potentials of CMfg are a growing field of interest which benefit from further research. The paper has focused on machine hosts because they are at the core of this CMfgPSS, but all stakeholders must be researched in further detail, as well as identifying further

potential target markets and revenue streams. It would also be valuable to provide

insight into the minimum number (critical mass) of networked equipment for the system

to be self-sustainable, and the optimal distance between networked hubs. The model

could be further developed to encompass more complex processes, such as electronics

manufacturing or Cloud Assembly (e.g. products assembled around the world by people

with spare time).

References

3D Hubs. n.d. *3D Hubs.* Accessed 11 24, 2016. https://www.3dhubs.com/.

Atlas Copco. 2016. *Pay per use: Cost effective tunneling in Portugal.* 06 09. Accessed 03 29, 2017. https://www.atlascopco.com/en-uk/mrba/customer-stories/stories---ure/pay-per-use-portugal.

Baines, T S, H Lightfoot, O Benedettini, D Whitney, and J M Kay. 2009. "The adoption of servitization strategies by UK-based manufacturers." *Journal of Engineering Manufacture* 224.

Baines, T S, H Lightfoot, S Evans, A Neely, R Greenough, J Peppard, R Roy, et al. 2007. "State-of-the-art in product-service systems." *Engineering Manufacture* 221.

Car2Go. 2017. *Car2Go.* Accessed 03 28, 2017. https://www.car2go.com/US/en/.

d'Herbemont, Oliver, Bruno César, Tom Curtin, and Pascal Etcheber. 2007. In *Managing Sensitive Projects: A Lateral Approach*, 23-38. New York: Routledge. Accessed 04 02, 2017. http://ic-pod.typepad.com/design_at_the_edge/2007/05/innovative_proj.html.

Dickson, P R. 1992. "Toward a general theory of competitive rationality." *Journal of Marketing* 56 (1): 69-83.

Electrolux. n.d. *Cost Per Cycle.* Electrolux. Accessed 04 02, 2017. http://professional.electrolux.co.uk/Solutions/Cost-Per-Cycle/.

European Union, C2NET. n.d. *C2NET.* Accessed 11 26, 2016. http://c2net-project.eu/.

European Union, CREMA. n.d. *CREMA.* Accessed 11 26, 2016. http://www.crema-project.eu/.

European Union, H2020 Research Project. n.d. *Cluster of H2020 Research Projects on Product Service Systems.* Accessed 11 26, 2016. http://www.fof-pss-cluster.eu/.

FabHub. n.d. *Find a digital fabricator.* Accessed 03 05, 2017. https://www.fabhub.io/directory.

Fictiv. n.d. *Fictiv.* Accessed 03 15, 2017. https://www.fictiv.com/.

Flynn, J, S Dance, and D. Schaefer. 2017. "Industry 4.0 and its Potential Impact on Employment Demographics in the UK." *15th International Conference on Manufacturing Research (ICMR).* London.

Gartner. 2016. *Gartner's 2016 Hype Cycle for Emerging Technologies.* 16 08. Accessed 03 16, 2017. http://www.gartner.com/newsroom/id/3412017.

Hilti. n.d. *Fleet Management.* Hilti. Accessed 04 02, 2017. https://www.hilti.co.uk/content/hilti/E1/GB/en/services/tool-services/fleet-management.html.

Hosono, S, and Y Shimomura. 2012. "Towards Establishing Mass Customization Methods for Cloud-compliant Services." *4th CIRP International Conference on Industrial Product Service Systems.* Tokyo.

Kerr, Wendy, and Chris Ryan. 2009. "Eco-efficiency gains from remanufacturing - A case study of photocopier remanufacturing at Fuji Xero Australia." *Journal of Cleaner Production* 75-81.

Li, B H, L Zhang, X Chai, F Tao, L Ren, Y Wang, C Yin, et al. 2014. In *Research and Application of Cloud Manufacturing in China*, edited by D Schaefer.

Li, B H, Zhang, L., S L Wang, Tao, F., J W. Cao, X D Jiang, X Song, and X D Chai. 2010. "Cloud manufacturing: a new service-oriented." *Journal of Computer Integrated Manufacturing Systems.*

Lindström, John, Magnus Löfstrand, Sean Reed, and Ahmad Alzghoulb. 2014. "Use of Cloud Services in Functional Products: Availability Implications." *6th CIRP Conference on Industrial.*

Lucas, Robert E., Jr. 2002. "The Industrial Revolution: Past and Future." In *Lectures on Economic Growth*, 109-110. Cambridge: Harvard University Press.

MakeTime. n.d. *MakeTime.* Accessed 03 28, 2017. https://www.maketime.io/.

ManuCloud. n.d. *Project Vision/Mission.* Accessed 03 23, 2017. http://www.manucloud-project.eu/index.php?id=186.

Manzini, E, and C Vezolli. 2003. *A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize.* J. Cleaner Prod.

Martin, E, and S Shaheen. 2016. "The Impacts of Car2go on Vehicle Ownership, Modal Shift, Vehicle Miles Traveled, and Greenhouse Gas Emissions: An Analysis of Five North American Cities." http://innovativemobility.org/wp-content/uploads/2016/07/Impactsofcar2go_FiveCities_2016.pdf.

Martinez, Veronica, Marko Bastl, Jennifer Kingston, and Stephen Evans. 2010. "Challenges in transforming manufacturing organisations into product-service providers." *Journal of Manufacturing Technology Management* 21 (4): 449-469.

McKinsey & Company. 2015. *Industry 4.0 - How to navigate digitization of the manufacturing sector.* McKinsey Digital.

Meier, H, R Roy, and G Seliger. 2010. "Industrial Product-Service Systems - IPS2." *CIRP Annals - Manufacturing Technology* (59): 607-627.

MFG.com. n.d. *MFG.com.* Accessed 03 17, 2017. https://www.mfg.com/.

Michelin. 2015. *Fleet Solutions.* Accessed 03 28, 2017. http://www.michelintruck.com/services-and-programs/michelin-fleet-solutions/.

Mont, O. 2001. *Introducing and developing a PSS in Sweden.* Lund University.

Mourad, M, A Nassehi, and D Schaefer. 2016. *Interoperability as a Key Enabler for Manufacturing in the Cloud, Procedia CIRP* 52: 30-34.

Mourad, M, A Nassehi, S Newman, and D Schaefer. 2017. "C-MARS-ABM: A Deployment Approach for Cloud Manufacturing." *15th International Conference on Manufacturing Research (ICMR).* London.

OpenDesk. n.d. *Digital Manufacturers to Contact and Work With.* Accessed 03 08, 2017. https://www.opendesk.cc/open-making/makers/.

—. n.d. *OpenDesk.* Accessed 03 29, 2017. https://www.opendesk.cc/.

Osterwalder, A, and Y Pigneur. 2010. *Business Model Generation.* Hoboken, New Jersey: John Wiley & Sons.

Osterwalder, A, Y Pigneur, G Bernarda, and A Smith. 2014. *Value Proposition Design.* New Jersey: John Wiley & Sons.

Philips. 2015. *Case Study: Circular Economy Lighting NUS.* Accessed 03 29, 2016. http://www.philips.com/a-w/about/sustainability/sustainable-planet/circular-economy/light-as-a-service.html.

Quinn, James Brian, Thomas L Doorley, and Penny C Paquette. 1990. "Beyond Products: Services-Based Strategy." *Harvard Business Review*, March-April Issue.

Rolls Royce. 2017. *Airline Care Services - Total Care.* Accessed 03 29, 2017. https://www.rolls-royce.com/products-and-services/civil-aerospace/aftermarket-services.aspx#carestore.

Schaefer. 2017. *Industry 4.0 – A Holistic Perspective, Steel Times International – Future Steel Forum Supplement,* June: 28-31.

Schaefer, D. 2014. *Cloud-Based Design and Manufacturing (CBDM): A Service-Oriented Product Development Paradigm for the 21st Century.* London: Springer. doi:ISBN 978-3-319-07397-2.

Singh Srai, Jagjit, Mukesh Kumar, Gary Graham, Wendy Phillips, James Tooze, Simon Ford, Paul Beecher, et al. 2016. "Distributed manufacturing: scope, challenges and opportunities." *International Journal of Production Research* 54 (23): 6917-6935.

Tukker, Arnold. 2004. "Eight Types Of Product–Service System: Eight Ways To Sustainability? Experiences From SUSPRONET." *Journal of Business Strategy and the Environment* (13): 246-260.

UPS. n.d. *Order Supplies and Forms.* Accessed 04 15, 2017. https://www.ups.com/content/us/en/resources/ship/packaging/forms.html.

Wallin, J., and I. Kihlander. 2012. "Enabling Product-Service System Development Using Creative Workshops: Experiences From Industry Cases." *International Design Conference - Design 2012.* Dubrovnik (Croatia).

Wang, L, and X V Wang. 2017. "Cloud-Based Cyber-Physical Systems in Manufacturing." 424pp. Springer.

Wong, M. 2004. *Implementation of innovative product service-systems in the consumer goods industry (PhD Thesis).* Cambridge University,.

Wu, Dazhong, David W Rosen, Lihui Wang, and Dirk Schaefer. 2014. "Cloud-Based Manufacturing: Old Wine in New Bottles?" *Proceedings of the 47th CIRP Conference on Manufacturing Systems.*

Wu, Dazhong, David W Rosen, Lihui Wang, and Dirk Schaefer. 2015. "Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation." *Journal of Computer-Aided Design* (59): 1-14.

Wu, Dazhong, J Lane Thames, David W. Rosen, and Dirk Schaefer. 2012. "Towards a Cloud-Based Design and Manufacturing Paradigm: Looking Backward, Looking Forward." *International Design Engineering Technical Conference & Computers and Information in Engineering Conference.* Chicago.

Wu, Dazhong, Matthew J Greer, David W Rosen, and Dirk Schaefer. 2013. "Cloud manufacturing: Strategic vision and state-of-the-art." *Journal of Manufacturing Systems* (32): 564-579.

Xerox. 2017. *Document Publishing and Production.* Xerox. Accessed March 16, 2017. https://www.xerox.com/en-us/services/communications-and-marketing/document-production.

Xu, Xun. 2012. "From cloud computing to cloud manufacturing." *Journal of Robotics and Computer-Integrated Manufacturing* (28): 75-86.

Zhang, L, Y Luo, F Tao, B H Li, L Ren, X Zhang, H Guo, Y Cheng, A Hu, and L Yongkui. 2012. In *Cloud Manufacturing: A new manufacturing paradigm*, Enterprise Information Systems 8(2) ,pp. 1-21.