Optimal pricing strategies for manufacturing-as-a service platforms to ensure business sustainability

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Abstract:

Manufacturing as a Service (MaaS) is a service which delivers manufactured products by connecting its network of suppliers with its customers on a digital platform. The long term sustainability of the MaaS platforms depends on their pricing strategy and whether they can generate sufficient volume from customers and encourage suppliers to do business with them. The objective of the paper is to develop optimal prices which a MaaS platform can charge to maximize its own profit as well as joint profit for itself and its supplier. Game theoretic models based on Hotelling's model are developed to determine the prices. We consider scenarios when the platform charges and does not charge subscription fees. We also determine conditions for the supplier to join the platform. Our models are motivated by real problems faced by a MaaS platform and have been validated using data provided by the platform. The models, the conditions developed and the insights obtained by validating the models using real data provide guidance to MaaS platforms to improve their business sustainability. The paper thus shows that MaaS platforms, when successfully designed, with appropriate pricing models can create an effective and economically sustainable business ecosystem.

Keywords: optimal pricing, Manufacturing as a Service (MaaS), spatial market, competition, platforms

1.0 Introduction

Multi-sided platforms (MSP) are technology-driven platforms that create value by enabling direct interaction between two or more customers or participant groups (Hagiu, 2013). MSPs in effect are ecosystems that allow stakeholders to interact using a technology platform to meet a business objective (e.g. economic success, social goal, etc). MSPs are also referred to as multi-sided markets that have increased in prominence with the rise of information technology and the Internet. Two-sided platforms are specific multi-sided platforms that bring together two distinct but interdependent groups of customers- the end-users and the suppliers and create value as intermediaries by connecting these groups (Eisenmann et al., 2006; Osterwalder et al., 2010). Manufacturing as a Service (MaaS), a specific two-sided platform, can be defined as a service that delivers manufactured products by connecting its network of suppliers with its customers on a digital platform. In MaaS, manufacturing the product itself has become the service. The shift to MaaS has become possible due to technological advances such as faster Internet, creation of platforms for collaboration, cheaper cloud resources, and increased connectivity (Roland Berger, 2019). Multiple MaaS platforms have emerged over the last few years, acting as aggregators linking a wide network of suppliers with the on-demand manufacturing needs of industrial customers. Some of these are focused on additive manufacturing (AM) technologies, while others provide a range of different manufacturing technologies. Some of these platforms are managed by large corporations like Siemens, Jabil etc while others are developed by specialized firms like 3D Hubs, XoMetry, Spareparts3D, Combiworks, Chizel etc. Such platforms help the industrial customers simplify their procurement process and provide them with access to qualified suppliers who can deliver quality parts on time. Although large companies have well-established procurement systems in place, it takes a lot of time and effort to procure a sizeable number of low-volume parts (Annunziata, 2019). Most of the suppliers are small and medium enterprises (SMEs), and they are typically reliant on a few critical customers. They have limited opportunities to expand their business and to utilize their spare capacity. To succeed, MaaS platforms need to guarantee quality and reliability and must have rigorous procedures to include new suppliers (Annunziata, 2019). Thus, MaaS platforms can provide opportunities to such suppliers to grow their business beyond their regular customers.

While the platforms do provide value to both suppliers and customers, it is not easy to convince the customers to use the platform for satisfying their manufacturing needs. A lack of sufficient volume of orders discourages suppliers from enlisting on the platform. There had been prior attempts to create platforms in the manufacturing industry. Van Alstyne et al. (2016) articulated that such platforms failed because they did not create the "right" value for the "right" user group. For example, Covisint, an online platform, was set up to match major automakers (e.g., Daimler-Chrysler, Ford, GM) with smaller auto-parts suppliers. Covisint failed because it created little value for participating suppliers when many suppliers had to compete for orders from a few automakers. As only a few suppliers participated, Covisint ended its operations in 2004 (Chen et al., 2018).

Research on platform services has primarily focused on business-to-consumer and consumer-to-consumer platforms (Evans, 2003; Chen et al., 2018). But, there is limited research on how MaaS can improve the sustainability of their business. A key decision that MaaS platforms have to make is pricing the parts which they deliver to the end-customers. The long term sustainability of the MaaS platforms in a fledgling market depends on their pricing strategy and whether they can generate sufficient volume from customers and encourage suppliers to do business with them. Established platforms may charge subscription fees to both customers and suppliers. But, when the market is in the early stage of development, the MaaS platforms may not be able to charge subscription fees for the customers and suppliers. They may instead price the parts sold over its platform as a mark-up over the price quoted by its suppliers on the platform. Such a pricing strategy may be necessary to encourage more customers and suppliers to use the platform and to generate sufficient volumes. A MaaS platform has to compete with other platforms and independent suppliers, who can supply directly to the customer- usually an Original Equipment Manufacturer (OEM) for a specific order. The OEM may have existing suppliers but face situations where there may be quality problems with an existing supplier, the supplier may not deliver urgent requirements or may not deliver in small lots. Facing such situations, OEMs may find it attractive to engage with MaaS platforms.

While MaaS platforms can develop costing models for different manufacturing processes to provide quotes to the customers, they lose certain orders for not matching the customer's price expectations for the desired quality and the lead time. One of the reasons why a first-principle based costing model may not work is the inability to incorporate competition. Hence, the objectives of this research are 1) to determine prices for every order which a MaaS can charge to maximise their profitability considering the competition for two scenarios- i) when it does not charge subscription fees and ii) when it charges subscription fees 2) to determine the conditions which ensure profitability for the suppliers to join the platform when the platform does not charge and charges subscription fees 3) to determine conditions which encourage the customer to share the platform's price with independent suppliers 4) to validate the platform's pricing model with data from a real wold MaaS platform and to draw insights about the applicability of the model.

We try to fulfill the objectives by developing game theoretic models based on Hotelling (1929), Balasubramanian (1998) and Kleer and Piller (2019). Our contribution lies in making the models realistic to support decision making by the MaaS platform so that apart from determining the prices, it can also find out i) when the suppliers are likely to join the platform, ii) the prices it can charge while maximizing the joint profits along with the supplier iii) under what condition is the customer expected to share the price quoted by the platform with other independent suppliers iv) how will the price quoted by the platform change if it charges subscription fees from customers and suppliers. The above realistics scenarios which a MaaS platform ix expected to face while conducting their business have not been covered in literature.

2.0 Literature Review

2.1 Distributed and cloud manufacturing

Manufacturing need not be organized in traditional structures of globalized mass production in centralized production facilities. Through decentralized production in distributed production facilities, goods can be delivered quickly and sustainably (Rauch et al., 2016). Some key characteristics of distributed manufacturing include digitalization, personalization or mass customization, localization, and use of new manufacturing technologies (Srai et al., 2016). MaaS helps in the adoption of distributed manufacturing, thereby enabling production on demand. Distributed manufacturing aims for flexibility, agility, and enhanced customer orientation in manufacturing building mass customization capabilities (Kohtala, 2015).

Cloud Manufacturing has been identified as one of the key pillars for realizing the vision of Smart and Distributed Manufacturing (Wu et al. 2015). Building on cloud computing capabilities, it aims to transfer a network of vertically and/or horizontally integrated manufacturing resources into capabilities and services which can be managed collectively. It may enable instant communication between multiple geographically dispersed manufacturing facilities, optimizing a network's value chain through bespoke recommendations (Charro and Schaefer, 2018). A diverse network of machines enables a wider range of manufacturing capabilities, based on exploiting enterprises' competencies (Wu et al. 2013). Qian et al. (2019) proposed a cloud manufacturing platform using both conventional and additive manufacturing technologies, which showed that the integrated platform could increase the utilization rate of resources while reducing energy consumption. But, the economic viability of distributed manufacturing is identified as a significant barrier to relinquish the traditional centralized economies-of-scale-based approach (Kumar et al., 2020).

2.2 Value generated by MaaS platforms

MaaS platforms provide opportunities by connecting users with a need to 3D print design with suitable (often high-quality, industrial-grade) AM systems in the proximity. Such a locally available manufacturing technology may reduce two key disutilities customers frequently face with solutions delivered from a centralized location.These are the inability to get a product that exactly fits a customer's specific requirements and a time lag or finite lead time to meet the demand (Kleer and Piller, 2019). B2B exchanges like MaaS should be considered as business service providers, whose role lies in the value they render to the user. In this sense, the services provided act as strategic inputs for participating firms. Since the value of any business service lies in making some business processes more competitive for users, a digital exchange can create a customer base only by providing this perceived impact. Conversely, unsuccessful exchanges fail when they are not able to provide any kind of perceived value to users (Ordanini, 2005). Thus, to be successful, platforms need to formulate two different value propositions—one for the end-user side and one for the business partners i.e., suppliers (Muzellec et al., 2015).

Hence, multi-sided platform businesses have to devise strategies to get multiple sides of the market on board and devise pricing, product, and other competitive strategies to keep multiple customer groups on a common platform (Evans, 2003).

Digital spare parts networks can be one type of MaaS platform. Some of the challenges in the adoption of digital spare parts networks were identified as an excessive need for post-processing, supplier quality parity, and ICT inadequacies (Chekurov et al, 2018). However, digital spare parts distribution could be applied to long-tail products, which will make excellent candidates for digital distribution (Chekurov et al., 2018).

2.3 Game-theoretic models in the context of digital manufacturing and platforms

Game-theoretical models for technology choice demonstrate that AM enables firms to serve multiple market segments. Thus, manufacturing firms or suppliers that increase their flexibility with AM are capable of serving fluctuating customer preferences while also strengthening their market dominance overtime (Weller et al., 2015). Kleer and Piller (2019) studied the effect of local production (enabled by AM) on consumer welfare, market structure, and competitive dynamics. They analyzed the trade-off between the instant availability of customized products manufactured by and near a consumer and the efficiency gains of realizing economies of scale by producing standard products in a central facility. Using two game-theoretical (Hotelling) models, Kleer and Piller (2019) showed that there is scope for improving consumer welfare arising from local production by consumer producers. But, Kleer and Piller (2019) did not specifically analyze the pricing strategies of MaaS platforms, which can produce parts using both conventional manufacturing and AM. Belleflamme and Peitz (2019) examined how two - sided platforms manage the external effects users exert on other users. In such situations, addition of one more seller increases buyers' willingness to participate but reduces the sellers′ willingness to participate due to competition. Thus, the authors analyze how competition within one group of users affects platforms′ decisions and the structure of markets with platforms. Such network effects are usually not typical for industrial products as industrial buyers will not like to disclose where they buy from unless the consumers influence them. Lin et al. (2020) analyzed a monopoly platform owner's two-sided pricing problem considering downward-trending production cost, product quality improvements, and consumers' strategic behaviours. Hagiu (2007) considered two polar strategies for market intermediation- "merchant" mode – buying from sellers and reselling to buyers - and "two-sided platform" mode –enabling affiliated sellers to sell directly to affiliated buyers. Such strategies are more suitable for consumer goods. A MaaS selling industrial products through its platform does act as a merchant but does not charge any affiliation fee. Moreover, it allows suppliers to deliver parts for specific orders directly to customers and pays the suppliers.

Sun et al. (2020) developed optimal pricing strategies for a 3D printing platform that sells standard and customized products with the platform and the designer seeking to maximize their profits, and the customer wishing to maximize their utility gained from the product purchase. The authors compared the platform's profit for two scenarios- one in which the platform allows the designer to add a mark-up and the other in which the platform sets the final price of the standard product and charges a commission fee as its revenue.

Choi et al. (2020), in their review of game theoretic applications in production research in the sharing and circular economy era also did not consider pricing for MaaS platforms.

2.4 Gaps from the literature review

There is limited literature on the pricing strategy of MaaS platforms which explores conditions for both the customers to buy parts and the supplier to sell parts using the platform. Kleer and Piller (201) provide the optimal prices and Sun et al. (2020) consider the options of standardized, and customized product where the designer has the opportunity to set prices for the design task for AM products. Belleflamme and Peitz (2019) considered network effects for their pricing models of two-sided platform, which may not be relevant for industrial products.

Neither Kleer and Piller (2019) nor Sun et al. (2020) provide conditions for the suppliers to join the platform. Both the papers did not determine conditions for the customer to share the price quoted by the platform with other independent suppliers. There is also limited research on the optimal subscription fees the platform can charge from its suppliers.

3.0 Model

We develop a game-theoretical model and its variant (one in which the MaaS platform does not charge subscription fees from its suppliers and customers and one in which it does) to model competition and to determine optimal prices, which the platform can charge. The models are based on the work of Hotelling (1929) and Salop (1979).The models are used to characterize the differentiation of the market. The differentiation ensures that the products offered by different suppliers (independent suppliers and MaaS) vary in some characteristics and therefore attract different customers. Thus, a manufacturer (OEM) has the option to procure parts from an independent supplier (can be an existing local supplier of the manufacturer or a new supplier) or from a MaaS platform.

The game is symmetric for the MaaS platforms. Therefore, it is sufficient to analyze the game on a circle segment of the size 1/N. The number of MaaS platforms present in the market constitutes N and influences the size of the market segment and thus, the intensity of competition between the 'N' MaaS platforms and an independent supplier. To avoid the asymmetric conditions faced by the competing firms at the extreme ends of a linear market and the one at the centre, we consider a circular market as suggested by Balasubramanian (1998). However, equilibrium prices, market shares, and profits of independent suppliers and the MaaS platform are sensitive to the presence of MaaS platforms for a particular part or product, which is captured by N. Thus, we consider that there are ‘N’ MaaS platforms located (exogenously) at equal distance from each other on the circumference. Customers are uniformly distributed on a circle of radius r and have an inelastic demand of ‘l’ for the part or product, equivalent to assuming a high reservation price compared to transportation cost (Figure 1). A key assumption in the models is that the OEM customers incur linear transportation cost ‘t’per unit travelled to the MaaS platform. The assumption of linear transportation cost is made to allow for model tractability as considering nonlinear costs can only change results algebraically but the intuition behind the model will be insensitive to the nature of these costs (Balasubramanian,1998). Transportation cost can be interpreted in multiple ways- as costs associated with a finite lead time associated with a lot of size ‘l’ or the waiting costs or the cost the customer is willing to pay for the lead time or the actual transportation cost if that is not included in the price. Thus, if the customer is willing to pay higher cost for a shorter lead time from the MaaS platform or MaaS charges a premium for shorter lead time, ‘t’ will be positive. The parameter μ captures the difference of preference fit of buying from the independent supplier or from a MaaS platform with respect to quality (expressed in units of l). Such distinction between quality and lead-time related costs is essential for the context of our models as the customer may incur a higher cost associated with a shorter lead time when buying from MaaS and higher cost of quality when buying from the independent supplier as MaaS ensures quality by certifying its suppliers. Kleer and Piller (2019) also consider μ in their adaptations of the models proposed by Salop(1979) and Balasubramian(1998) though they do not provide the interpretation for it. Thus, for our model setting, customers also have preferences for certain levels of quality and incur costs associated with quality μ for the independent supplier. μ will be positive if there is a higher cost associated with achieving same level of quality from the independent supplier because of rework, additional post-processing or costs incurred by the customer for visits to the independent supplier to make the part exactly to match requirements.

Gross utility derived from procuring the part is u. The cost of producing ‘l’ units is c_i (l)·l. In order to capture economies of scale in production, we use the cost function for supplier affiliated with platform (sp), for an independent supplier ‘s’. This represents a production function with fixed costs f_i and constant marginal costs m_i. P_p and P_s are the prices charged by the platform and the independent supplier respectively.

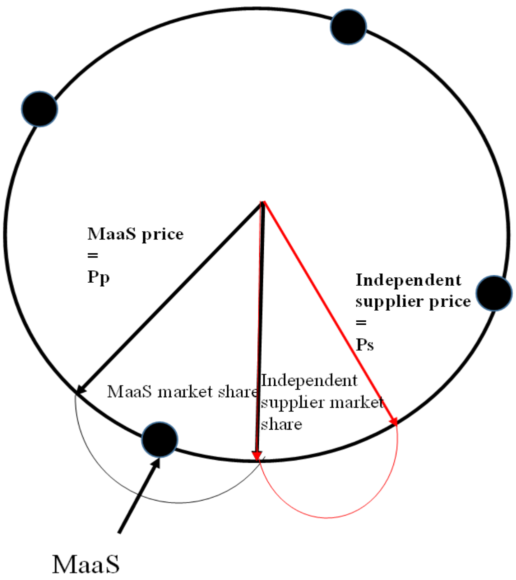

Figure1: Competition in the spatial market

All parameters notations are defined and shown in Table 1 below

Table 1 : Model parameters and notations

Parameters used	**Description of the parameter**
l	Quantity bought by the customer
t	Costs associated with a finite lead time associated with a lot of size 'l' or the waiting costs or the cost, the customer is willing to pay for the lead time or the actual transportation cost if that is not included in the price
μ	difference of preference fit of buying from the independent supplier or from a MaaS platform with respect to quality
C_{sp}	Unit cost of the supplier affiliated to the platform
m_s	Unit cost of the independent supplier
N	Number of competing MaaS platforms
α	Percentage mark-up charged by the MaaS platform
φp	minimum market share which a supplier will expect to affiliate with the MaaS platform
γ, β	Ratio between m_s and C_{sp} and P_s and C_{sp} respectively where γ and β can vary between 0 and 1
F	annual subscription fees which the MaaS platform charges from customers
F_s	annual subscription fees which the MaaS platform charges from suppliers, which affiliate to the platform
n_p	Annual number of orders for which the customer engages with the MaaS platform

$\varphi p''$	Marketshare of the MaaS platform when it charges subscription fees
Notations for the different prices	
P_p	Price charged by the MaaS platform
P_s	Price charged by the independent supplier
P_p'	Price charged by the platform when trying to maximize joint profit for itself and its suppliers
P_{pL}	Price which the platform charges when it leads and which is disclosed to the independent supplier, which follows
$P_{p''}$ and $P_{s''}$,	Prices charged by the platform and the independent supplier when the platform charges subscription fees.

3.1 Incentive for a manufacturer to procure parts through the platform

Utility a manufacturer (customer) derives from buying from the platform at distance *x* is

$U_P = u - P_p * l - t * x * l$, where donates the direct utility of (l units of) the product, $P_p$is the price charged by the platform , l is the quantity bought and t·x·l the total transportation cost.

In contrast, the utility which the manufacturer derives from an independent supplier is

$U_s = u - P_s * l - \mu * l$, where P_s is the price charged by the independent supplier and $\mu * l$ is the cost of misfit due to quality.

The manufacturer will be indifferent in choosing between the platform and the independent supplier if

$P_p + t * x = P_s + \mu$

$x = (P_s + \mu - P_p)/ t$

In each segment, two MaaS platforms competes with an independent supplier. Solving the OEM customer's indifference equation for x (the customer located at x is the one who is just indifferent between the two options) leads to the platform's market share of

$\varphi p = 2x = 2*(P_s + \mu - P_p)/ t$ as the platform faces competition on either side (Figure 1)

Thus, the platform's profit = $\pi_p = [P_p - C_{sp}]* [2*(P_s+\mu - P_p)/ t]*l - f_p$

The independent supplier captures the remaining profit

$=\varphi_s = 1/N - 2*(P_s+\mu - P_p)/ t$ leading to a total profit of

$\pi_s = (P_s - m_s)*[(1/N ^- 2*(P_s+\mu - P_p)/ t]*l - f_s$

$C_{sp} = (f_{sp}/l + m_{sp})$

$\pi_p =[P_p - C_{sp}]* [2*(P_s+\mu - P_p)/ t)]*l - f_p$

$$\frac{\delta\pi_p}{Pp} = 2\left[P_s - 2P_p + C_{sp} + \mu\right]\left(\frac{l}{t}\right) = 0$$

Thus, $P_p = (P_s + C_{sp} + \mu)/2$……………………………………………(1)

$$\frac{\delta\pi s}{Ps} = \frac{1}{N} - 2\left(\frac{1}{t}\right)[2P_s - P_p + \mu - m_s] = 0$$

Thus, $P_s = (P_p + m_s - \mu)/2$ + t/4N……………………………………(2)

Solving (1) and (2), we get $Pp = (m_s + \mu + 2C_{sp})/3$ + (t/6N)…………(3)

Thus, the optimal price which the platform can charge increases with increase with μ and t as well as increase in the marginal cost of the independent supplier m_s and the price charged by the supplier affiliated to the platform C_{sp}.

Thus, (1+α/100) C_{sp}=(m_s+μ+2C_{sp})/3 + t/6N, where α is the percentage mark-up charged by the platform.

Thus, $\frac{\alpha}{100} = (m_s + \mu)/3C_{sp}$ + t/(6N*C_{sp})- 1/3 ……………………..(4)

Thus, higher the cost of quality associated with the independent supplier and higher is the cost the customer is willing to pay due to lead time difference, the platform can charge higher mark-up.

If $\mu = 0$, $\frac{\alpha}{100} = m_s/3C_{sp}$ + t/(6N*C_{sp})-1/3
If t = 0 i.e there is no cost difference due to lead time and no cost of quality difference between the independent supplier and the platform, the mark-up which a platform can charge will be only proportional to the ratio of the marginal cost of an independent supplier and the cost of a supplier on the platform.

Similarly, P_s= t/3N + ($2m_s - \mu + C_{sp}$)/3…………………………(5)

Thus, P_s will decrease with increase in μ.

3.2 Incentive for a supplier to sell parts using the platform

Seller's utility while selling parts through the platform is
$(C_{sp} - m_s)$ * 2($P_s - P_p$+μ)/ t

Seller's utility when selling independently is (P_s- m_s)*[1/N- 2($P_s - P_p$ +μ)/ t] assuming the marginal cost for both the independent supplier and the supplier on the platform is same.

Hence, the seller will be willing to affiliate to the platform if

$(C_{sp} - m_s)$ * 2($P_s - P_p$+μ)/ t ≥ (P_s- m_s)*[1/N- 2($P_s - P_p$+μ)/ t]

i.e. $(C_{sp} - m_s)$/ (P_s-m_s) ≥ [1/N- 2(P_s-P_p+μ)/t]/[2(P_s-P_p+t)]

Thus, $(C_{sp} - m_s)/(P_s - m_s) \geq (1/N - \varphi p)/\varphi p$ ……….………………………………..(6)

If $m_s = \gamma C_{sp}$ and $P_s = \beta * C_{sp}$, where γ and β can vary between 0 and 1

Simplifying (6), we get the minimum market share which a supplier will expect to affiliate with the platform

$\varphi p \geq [(\beta - \gamma)]/[N * ((1 - \gamma) + \beta - \gamma)]$……………………………………………(7)

If the marginal cost of the supplier while supplying on the platform is different from that while delivering independently and is equal to $m_{sp} = \gamma' C_{sp}$

then, $\varphi p \geq [(\beta - \gamma)]/[N * ((1 - \gamma') + \beta - \gamma)]$……………………………………..(8)

Thus, the platform can be confident that the supplier will be willing to participate if condition (7) or (8) is valid.

3.2.1 Maximizing joint profits for the platform and suppliers on the platform

$\pi_{sp} = [C_{sp} - m_{sp}] * [2*(P_s + \mu - P_p')/(t)]*l - f_{sp}$ where P_p' is the price charged by the platform when trying to maximize joint profit for itself and its suppliers

Thus, combined profit of the platform and the supplier on the platform will be $\pi_p + \pi_{sp}$ $= [P_p' - m_{sp}] * [2*(P_s + \mu - P_p')/t]*l - f_p - f_{sp}$…………………………………………(9)

Differentiating (8) with respect to P_p' and equating to 0 and by using (2),

We get P_p' which will maximize combined profit

$= (3m_{sp} + \mu)/3 + t/6N$…………………………………………………………(10)

Thus, to maximize joint profits for the platform and the supplier on the platform, the platform's price will be dependent on the marginal cost of the supplier m_{sp} instead of the price quoted by the supplier on the platform C_{sp} .

Also P_p' will be less than P_p if $m_{sp} < (m_s + 2C_{sp})/3$

3.3 Pricing for the platform if it is the leader and the independent supplier follows

There can be a possibility that the platform's price is shared with the independent suppliers (if they are existing suppliers and have good relationship with OEMs). In such a situation, the platform has to determine the independent supplier's optimal price, insert it into its own profit function and then determine its optimal price.

Thus, inserting P_s into π_p and differentiating with respect to P_{pL}, we get P_{pL} where P_{pL} is the price which the platform charges which is disclosed to the independent supplier

$P_{pL} = t/4N + \mu/2 + (m_s + C_{sp})/2$……………………………………………(11)

and

$P_{sF} = (3 * t)/8N - \mu/4 + (3m_s + C_{sp})/4$ ……………………………………(12)

where P_{sF} is the price when the independent supplier can observe the platform's price and respond.

The customer will be willing to share the platform price to the independent supplier if $P_{sF} < P_s$ and $P_{pL} > P_{sF}$

Using (5), (11) and (12), we get the conditions as

$t < 2N(C_{sp} - m_s - \mu)$…………………………………………………(13)

And $t < 2N(3\mu + C_{sp} - m_s)$……………………………………………(14)

(13) and (14) can be true at the same time if $\mu = 0$ i.e there is no additional cost of quality for the independent supplier . If $\mu > 0$, then only (13) will be binding.

If $\mu < 0$, then only (14) will be binding.

But, some customers may be willing to give the order to the independent supplier if $P_{pL} \geq P_{sF}$ and $P_p \leq P_s$ i.e if the price of the platform was less than that of the independent supplier for simultaneous determination of prices by the platform and the independent suppliet but the price of the independent supplier becomes less than that of the platform in the leader-follower game. This will be true if

$2N(2\mu + C_{sp} - m_s) < t < 2N(3\mu + C_{sp} - m_s)$…….(15)

or if $2\mu < t < 3\mu$ ……………………………………(16)

Thus, the platform should be alerted if they observe the above conditions, which will essentially imply that a competing independent supplier can potentially price them out of competition by receiving the platform's pricing information from the customer.

3.4 Pricing of products when the platform charges subscription fees from both the customers and suppliers

Let F be the annual subscription fees which the platform charges from customers and n_p be the annual number of orders for which it engages with the platform and the prices charged by the platform and the independent supplier be $P_{p''}$ and $P_{s''}$.

Then the customer will subscribe to the platform if for every individual order of ordering quantity l

$$(P_{p''} + tx) * l + \frac{F}{n_p} = (P_{s''} + \mu) * l$$

Thus, $x = [(P_{s''} - P_{p''}) + \mu - \frac{F}{n_p * l}]/t$

And the marketshare which the platform will obtain $\varphi p'' = [2*(P_{s''} - P_{p''}) + \mu - \frac{F}{n_p * l}]/t$

Thus, profit for the platform when it charges subscription fee will be $\pi_{p''} =$

$$[P_{p''} - C_{sp}] * [2*(P_{s''} + \mu - P_{p''} - \frac{F}{n_p * l})/t] * l - f_p \ldots\ldots (17)$$

Differentiating π_p'' with respect to $P_{p''}$ and equating it to zero, we get

$$P_{p''} = (P_{s''} + \mu + C_{sp} - \frac{F}{n_p * l})/2$$

Profit for the independent supplier when the platform charges subscription fee will be

$$\pi_{s''} = (P_{s''} - m_s) * [(1/N - 2*(P_{s''} + \mu - P_{p''} - \frac{F}{n_p * l})/t] * l - f_s \ldots\ldots (18)$$

Differentiating π_s'' with respect to $P_{s''}$ and equating it to zero, we get

$$P_{s''} = t/4N + (P_{p''} - \mu + m_s + \frac{F}{n_p * l})/2 \ldots\ldots (19)$$

Solving for $P_{p''}$ and $P_{s''}$, we get

$$P_{p''} = t/6N + (\mu + 2C_{sp} + m_s)/3 - \frac{F}{3(n_p * l)} \ldots\ldots (20)$$

Thus, higher the subscription fee, the platform intends to charge from the customer, the lower will be the price it can charge for each order.

and $P_{s''} = t/3N + (1/3)*(C_{sp} + 2m_s - \mu + \frac{F}{(n_p * l)}) \ldots\ldots (21)$

Thus, the independent supplier can increase its price in proportional to the subscription fee which the platform charges its customers.

If the platform also charges annual subscription fee of F_s from each supplier, which affiliates to the platform, and the supplier gets n_s orders in a year through the platform, the supplier will affiliate to the platform if

$$[C_{sp} - m_s - F_s/(n_s * l)]/(P_{s''} - m_s) \geq (1/N - \varphi p'')/\varphi p''$$

If $m_s = \gamma\, C_{sp}$ and $P_{s''} = \beta' * C_{sp}$, we get

$$\varphi p'' \geq [C_{sp} * (\beta' - \gamma) * n_s * l]/[N * C_{sp} * n_s * l * (1 + \beta' - 2\gamma) - N * Fs]$$

Thus, to have a positive $\varphi p''$ *and if* $\beta' > \gamma$, then we get the condition for the maximum subscription fee which the platform can charge the suppliers

$$N * C_{sp} * n_s * l * (1 + \beta' - 2\gamma) - N * Fs > 0$$

$(F_s / (n_s * l)) < C_{sp}(1 + \beta' - 2\gamma)$……………….(22)

Thus, we can get a bound on the maximum subscription fees the platform can charge from the suppliers. (22) is suitable for the condition when the supplier wins repeat orders for the same part.

3.5 Uniqueness of the proposed pricing models

The model to determine the optimal prices for the MaaS platform is based on Hotelling (1929) and Salop (1979), later applied by Balasubramanian (1998) and Kleer and Piller (2019).

The optimal prices which a MaaS platform can charge should take into account the needs of both the customers and the suppliers and should try to optimise the joint profits for the platform as well as the suppliers. The prices also need to be updated based on customers' relative preferences for lead time and quality. There can also be a situation that a platform quoted price may be shared with an independent supplier and the MaaS platform must be prepared to update prices or reject such orders. A MaaS platform may move from an individual order based pricing to a subscription model and hence need to rework its optimal price. All the above realistic considerations have not been considered in literature.

Hence, the unique features of our models by enhancements of the basic Hotelling model are highlighted below. 1) The model derives the conditions for the suppliers to join the platform and calculates the expected market share. Conditions for the suppliers to join the platform by maximizing suppliers' profit have not been attempted in the literature before. 2) The model maximizes joint profits for the platform and the suppliers on the platform. Such joint profit maximization has also not been considered in the literature. 3) The model includes a scenario where the platform is the price-leader and the independent supplier follows i.e when the platform's price is made available to an independent supplier. This situation is also realistic as a potential customer may quote a platform quoted price with its own suppliers with the intention to maximize its gain. Without considering such situation, the platform may unsuccessfully bid for an order. 4) The model also determines the prices when the platform charges subscription fees from both the customers and suppliers. This not only allows the platform to determine prices when it is charging subscription fees as well as to determine maximum subscription fees it can charge from the suppliers.

4.0 Validation of the model: a case study

4.1 Background and value proposition offered by Chizel

Chizel is an Indian B2B Cloud Manufacturing Platform that aims to empower and digitalize SMEs of India involved in manufacturing of plastic and metal parts. The MAAS provided by Chizel is an end-to-end service where buyers can place an order on Chizel and get competitive cost and quality assured parts delivered at their doorstep. Chizel offers services across multiple manufacturing technologies – five AM technologies and conventional manufacturing technologies like CNC Machining, Injection Moulding, Vacuum Casting, Sheet Metal Fabrication, Casting and Forging and also includes post-processing operations. Every supplier, interested in affiliating with Chisel fills out a form. Then after initial checking, Chizel conducts audit, rates the suppliers and selects them. Currently they have qualified 200 suppliers from Western and Southern part of India out of around 500, which had shown interest. The current procurement workflow for the OEMs is very traditional. They have their existing private supplier network to whom they send the customer drawings along with the quantity and lead time. Suppliers refer to drawings, conduct the process analysis and then come up with quotations considering multiple factors like the machine's availability, the criticality, quantity and relationship, and trust. The customer evaluates the price quotations, sometimes using their own Total Cost of Ownership (TCO) model, and places the order. MaaS offered by Chizel provides flexible capacity, real-time monitoring and transparency. Along with MaaS, Chizel also offers Chizel Procure - a solution for automating the procurement workflow, which they offer for free to their OEM customers and also suppliers. Using their own expertise, Chizel is developing its own first-principles costing model for each of the different manufacturing technologies. Based on its cost model and understanding of customer priorities, Chizel charges a mark-up percentage on the price quoted by one of its suppliers, which it selects out of quotations obtained from 2 or 3 suppliers on its platform. But, the challenge is that despite its best efforts, Chizel still loses orders as customers believe that the price quoted by Chizel are higher than their expectation. Chizel's win percentages are 30% for conventionally manufactured rush orders (customers ask for faster delivery), 40% for additively manufactured rush orders, and 10% and 30% respectively for conventionally manufactured orders and additively manufactured orders respectively with normal lead time expectations. Loss of orders can also discourage suppliers to provide their services through the platform. Hence, inability to win orders and loss of suppliers will impact the long term business sustainability of Chizel.

4.2 Validation of the proposed models for the case study

The MaaS pricing models developed in this research were validated using data from orders which Chizel tried to fulfil. Whether Chizel got the order or not was also available to the research team. Data was obtained for different orders requiring traditional manufacturing processes (Table 2) and additive manufacturing processes (Table 3). C_{sp} was known to Chizel while it estimated t and μ and m_s.

From Tables 2 and 3 (all cost and prices in Indian Rupees), we can find that the modelled price very closely matches the price quoted by Chizel for the orders which Chizel won. For the orders it did not win, the calculated price from our model was significantly lower than the price quoted by Chizel, thereby explaining why Chizel did not get the order. For part identifier 866 in Table 2, the calculated price was marginally higher than Chizel's quoted price but still, Chizel did not get the order as the customer's price expectation was possibly lower. For part identifiers 889, 893, 870 and 907, the calculated prices were marginally lower than the Chizel's quoted prices, but Chizel did win the orders suggesting that the price quoted by Chizel were lower than the price the customer was willing to pay.

The data also shows some pattern about t and μ. For example for parts produced using conventional manufacturing and shorter lead time requirement, t lies between 0.91-1.0 , while μ were clustered around 0.24, 0.30 and 0.60 of the price quoted by the supplier on the platform. For parts produced using conventional manufacturing and normal turnaround time, t lie between 0.4 to 0.53 of the price quoted by the supplier on the platform while μ were clustered around 0.24, 0.31 and 0.39 of the price quoted by the supplier on the platform. For parts produced using AM and with faster lead time requirement, t lies between 0.91-0.99 of the price quoted by the supplier while μ were clustered around 0.45, 0.57, 0.63 and 0.69 of the price quoted by the supplier, except for one outlier part 918, where t was 3.1 times the price quoted by the supplier and μ were 1.55 times that of the price quoted by the supplier. For parts produced using AM and with normal lead time requirement, t lies between 0.6-0.80 of the price quoted by the supplier with one outlier part where it was 0.99 of the price quoted by the supplier and μ were clustered around 0.29, 0.34 and 0.50 of the price quoted by the supplier. Thus, for parts produced using conventional manufacturing and AM and for faster and normal lead time requirements, t lie in a relatively narrow band compared to the range for μ.

We also analysed the margins which the platform could earn for the parts produced using conventional manufacturing and those using AM for both the orders the platform won and did not win. For parts produced using conventional manufacturing and fast turnaround time requirement for which the platform won the orders, the calculated mark-up percentages were 23 and 18% respectively while for the orders which they did not win, the calculated mark-up percentages were 10, 28 and 37% while the platform intended to charge 5.5, 55 and 68% respectively. For parts produced using conventional manufacturing and normal turnaround time requirement for which the platform won the orders, the calculated mark-up percentages were 8, 9 and 16% while for the orders which they did not win the orders, the calculated mark-up percentages were 12 and 16% respectively. Thus, the platform intended to charge much higher for those orders, thereby justifying the reason for them not to win the orders.

Table 2 Comparison of calculated price and price quoted by platform for parts manufactured using traditional manufacturing processes

Part Identifier	m_s	C_{sp}	t	μ	N	Calculated P_p	Price quoted by the platform	Whether platform got the order	Customer's lead time expectation	Order Quantity
893	1450	1672	1600	1000	2	2064	2083	YES	FAST	6

897	1110	1182	1100	450	2	1400	1394	YES	FAST	36
859	214	179	180	70	2	229	277.5	NO	FAST	14
866	175	209	190	50	2	230	220	NO	FAST	10
945	833	650	600	400	2	894	1092	NO	FAST	48
803	5500	5749	2400	1200	2	6266	6250	YES	NORMAL	2
863	6.5	5.83	3	1.5	2	6.8	6.4	YES	NORMAL	100
896	275	306	125	75	2	331	331	YES	NORMAL	8
901	160	190	100	75	2	213	367	NO	NORMAL	3
805	1667	1598	800	500	2	1854	2019	NO	NORMAL	120

For parts produced using AM and fast turnaround time requirement for which the platform won the orders, the calculated mark-up percentages were 22 % for two orders and 32 and 70% for the other two orders while for the orders which they did not win, the calculated mark-up percentages was 21% but the platform charged much higher. For parts produced using AM and normal turnaround time requirement for which the platform won the orders, the calculated mark-up percentages were 16, 18 and 21% while for those which it did not win, the calculated mark-up percentages were 7, 11,11 and 15% respectively. Thus, overall we can summarise that mark-up percentages will be lowest for conventionally manufactured parts with normal turnaround requirements. The mark-up percentages for AM produced parts with normal lead-time can be similar to those for conventionally produced parts with fast turnaround time requirements while for some of those parts, margins can also be similar to those of conventionally produced parts with normal lead time requirements. The margins can be highest for AM produced parts with fast turnaround-time requirements.

Table 3: Comparison of calculated price and price quoted by platform for parts manufactured using additive manufacturing processes

Part Identifier	m_s	C_{sp}	t	μ	N	Calculated P_p	Price quoted	Whether platform	Customer's lead time expectation	Order quantity

							by the platform	got the order		
881	600	697	680	400	2	855	844	YES	FAST	12
889	100	126	125	80	2	155	161	YES	FAST	55
918	150	193	600	300	2	329	330	YES	FAST	22
993	600	583	560	400	2	769	767	YES	FAST	15
994	475	500	450	225	2	604	800	NO	FAST	1
870	1000	1200	950	600	2	1413	1467	YES	NORMAL	3
907	180	202	200	100	2	245	263	YES	NORMAL	8
1015	700	735	550	250	2	853	850	YES	NORMAL	24
884	250	340	250	100	2	364	489	NO	NORMAL	200
908	2500	2960	1800	1000	2	3290	3640	NO	NORMAL	2
895	4000	4950	3500	1750	2	5508	6250	NO	NORMAL	2
995	1500	1766	1250	750	2	2032	2312	NO	NORMAL	50

We also conducted analysis of how the prices charged by Chizel will change if it tries to maximize the combined profit of itself and its supplier. We requested Chizel to provide estimate of its supplier's marginal cost and used it to determine the price it can charge when maximizing joint profit. We can find from the results, shown in Table 4 that for conventionally manufactured parts, by reducing prices while maximizing joint profits, Chizel could actually maximize its profit as its market share increases except for one part no. 945, where the profit marginally reduces as the reduction in price did not result in significant increase in marketshare. Obviously, it will depend on whether the condition mentioned in section 3.2 is valid or not. Similar results are obtained for AM parts (as shown in table 5). Only Part no. 895 experienced an increase in price due to joint profit maximization and its profit marginally reduces compared to the case when the platform maximizes its own profit. This happens as the marginal price of the supplier supplying to the platform violates the condition shown in section 3.2

Table 4: Prices and profits for conventionally manufactured parts while maximizing joint profits

Part Identifier	m_s	m_{sp}	C_{sp}	Calculated P_p when maximizing platform profit	Calculated $P_{p''}$ when maximizing joint profit	Actual Price quoted by the platform	Profit for platform profit maximization	Profit for joint Profit maximization
893	1450	1550	1672	2064	2017	2083	1157	1542
897	1110	1150	1182	1400	1392	1394	3099	3571
859	214	160	179	229	198	277.5	392	481
866	175	190	209	230	223	220	48	98
945	833	645	650	894	828	1092	9560	9110
803	5500	5600	5749	6266	6200	6250	445	583
863	6.5	5.6	5.83	6.8	6.4	6.4	63	71
896	275	300	306	331	335	331	80	94
901	160	175	190	213	208	367	33	57
805	1667	1700	1598	1854	1733	2019	19720	26386

Table 5: Prices and profits for additively manufactured parts while maximizing joint profits

Part Identifier	m_s	m_{sp}	C_{sp}	Calculated P_p when maximizing platform profit	Calculated $P_{p''}$ when maximizing joint profit	Actual Price quoted by the platform	Profit for platform profit maximization	Profit for joint Profit maximization
881	600	650	697	855	840	844	877	1155
889	100	110	126	155	147	161	705	1171
918	150	180	193	329	330	330	1348	1478
993	600	560	583	769	740	767	1844	2067
994	475	475	500	604	588	800	48	60
870	1000	1000	1200	1413	1279	1467	285	609
907	180	180	202	245	230	263	146	229
1015	700	700	735	853	829	850	1205	1588
884	250	290	340	364	344	489	940	3820
908	2500	2800	2960	3290	3283	3640	242	361
895	4000	4850	4950	5508	5725	6250	356	342
995	1500	1600s	1766	2032	1954	2312	5634	9717

4.3 Summary of findings from the case study

The results showed that price calculated by the model very closely matched the price quoted by Chizel for the orders which it won and was significantly lower than the price quoted by Chizel for the orders it did not win. The results also showed that the mark-up which the platform can charge can be AM produced parts with fast turnaround-time requirements and lowest for conventionally manufactured parts with normal turnaround requirements. The mark-up percentages for AM produced parts with normal lead-time can be similar to those for conventionally produced parts with fast turnaround time requirements. The results also showed that the platform can maximize its profit while trying to maximize the joint profit along with the supplier as reduction in prices will result in higher market share.

We can also conclude that accuracy by which the platform can determine the prices and hence the mark-up percentages will depend on to what extent they can estimate customer's preference to pay for faster lead time compared to a competitor and to what extent customer values quality differences or the costs associated with the same levels of quality.

5. Conclusion

The contribution of this research lie in 1) deriving the conditions which are needed for the suppliers to affiliate with the platform when the platform does not charge or charges subscription fees from the supplier, 2) determining the conditions under which the customer is expected to share the platform's price to the independent supplier and 3) determining the prices when maximizing the joint profits for the platform and the supplier 4) determining the maximum subscription fees which the platform can charge from the supplier.

Validation of the pricing model with the real world MaaS platform demonstrates that it is possible to consider competition and accurately determine the prices, the platform can charge for each order using competition in a spatial market. Thus, the first-principles cost plus pricing model, which a platform might use can be used in conjunction with the competitive model for validation. When there are significant differences between the proposed pricing and the first-principles cost plus pricing model, the platform should be well advised to follow the competitive pricing model to improve the order win percentage and improve its business sustainability. The condition under which the customer is expected to share the platform's pricing information to the competing independent suppliers by considering a leader-follower game can alert the platform for the orders it may decide not to compete on.

Thus, our research will provide valuable guidance for MaaS platforms to ensure that they are able to attract both suppliers and customers and hence remain viable. When they are confident enough to generate enough volumes for the suppliers and to provide continued benefits to their customers, they can potentially move to a subscription-based business model.

It is also clear from the Chizel case study that platforms can create value for both suppliers and customers. For Chizel, the end-to-end services were supported by reliable suppliers, flexible capacity, and real-time transparency to create a business ecosystem for over 2000 manufacturing companies. While not within the remit of the scope of this paper, it is important to note that platforms can create effective and powerful ecosystems for businesses to collaborate and to gain competive advantage (Nucciarelli et al, 2017). Thus, there are opportunities for future research to enhance the competitiveness and business sustainability of MaaS platforms.

Potential avenues for future research can be

1. to analyse the large amount of data from the orders which the MaaS platforms win and do not win and use those to estimate the reservation prices or the maximum prices, customers will be willing to pay for specific types of orders. The orders can be classified and clustered by order quantity, lead times, types of manufacturing process needed, usage (spare parts, production parts, prototypes etc). Such reservation prices can be the upper bounds for the prices which a platform can charge. This can help in analysing how prices from models like ours or those suggested by Kleer and Piller (2019) and Sun et al. (2020) compare with the above empirically derived reservation prices.
2. to quantify the benefits which an industrial OEM can generate by using MaaS platforms, providing services involving both conventional and AM processes or specialised AM platforms.
3. to determine the demand which is needed by the MaaS platform before it can decide to move to a subscription-based pricing model.
4. to consider learning effects of suppliers to improve quality, lead time and also to reduce costs and to provide pricing targets to suppliers to win orders.

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