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The Degree of Mass Personalisation under Industry 4.0

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Abstract

We have entered an era of personalisation at scale, but product lifecycle has not developed adequately to achieve highest customer satisfaction. Review literature in a wide range of business and industries shows that mass production cannot fulfil the market demand. This paper investigates the degree of mass personalisation (DoMP) based on the critical personalisation factors in the contexts of Industry 4.0. A model has introduced to analyse and measure DoMP following by an algorithm to tailor products for meeting effective mass personalisation. A definition for DoMP along with a comparison of mass customisation, personalisation, and mass personalisation have provided. Finally, challenges and future perspectives identified and discussed. This study has potential application in personalisation as a service (Pa^2S).

Keywords: Industry 4.0; Personalisation; Internet of Things; Product Design

1. Introduction

The fourth industrial revolution has profoundly transformed the world and described new data-driven manufacturing in mass customisation and personalisation. In the era of digital transformation, when customers' petition is tailored, affordable and high-quality products, the market is not limited to the low price competition. Personalisation becomes a critical success factor for industries and business sectors. Providing a unique customer experience is essential for almost all business sectors. Personalisation is critical in some business sectors such as medical and healthcare. However, personalisation becomes a common requirement for industries due to close business competition. The ultimate goal is to transform the data into valuable information for the highest customer satisfaction. The value of data in manufacturing significantly upraised due to the Industry 4.0 paradigm. However, extracting highest value from manufacturing data is a challenge [1]. Although tech companies have dominated personalisation in cyberspace, they have serious challenges to make affordable and personalised products in the physical world. To meet customer satisfaction, tailoring products and services (P&S) has involved the highest customisation. Therefore, researchers are looking for Industry 4.0 capabilities and potential for the highest changes in a product. Personalisation has heavily deployed in additive manufacturing, cyberspace, digital and new media. Other industries have not utilised the state-of-the-art technologies to meet affordable personalisation with acceptable delivery time and quality. The personalisation was not feasible enough as in

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mass production before the fourth industrial revolution. Emerging Industry 4.0 technologies such as the Internet of Things (IoT) have developed an integrated platform with real-time connection and access to the Cloud storage and computing process. IoT offered considerable value for transforming products toward personalisation paradigm. More progress has perceived smart products and systems such as wearables, homes, transportation, manufacturing, agriculture, supply chain, healthcare, and energy. Due to frequent changes in individual preferences, dealing with adjustments is one of the most critical situations. Therefore, personalisation involves internal (what a person needs) and external (environmental) data collection. In both scenarios, product personalisation may regularly affect by changes. IoT along with other Industry 4.0 technologies play a vital role in data collection for giving unique customer experiences. This paper aims to address an essential question. How to develop a formula for DoMP in the content of Industry 4.0 and what key technologies may be considered for mass personalisation? This study considered some factors involved in personalisation as a service (Pa^{2}S). By using Industry 4.0 technologies in which customers will have a real-time view of any extra cost associated with a product specification. Although Industry 4.0 has proposed effective mass personalisation, the degree of mass personalisation has a mutual impact on customers and providers. Therefore, a compromise between the level of personalisation and effort is crucial for making a decision. This paper organised as follows. Section 2. gives a literature review related to the study under categories including Industry 4.0, mass personalisation and mass customisation; Section 3. presents definitions and concepts of mass customisation, personalisation, and mass personalisation; Section 4. demonstrates a mathematic formula for the degree of mass personalisation (DoMP); Section 5. challenges and future perspectives; Section 6. Finally, conclude the main contribution and research direction.

2. Literature Review

Industry 4.0, a German strategic has identified a transformation from mass production to personalisation across resources including humans, machines, and sensors [2]. Some personalisation approaches have used for product customisation as customer's requirements are often ambiguous [3]. Customer study behaviour has been an attractive topic in the psychological to predict trends. In a personalisation scenario, the focus has to act from a passive to a smart approach [4]. Relationship of customers' requirements and product choices are very complicated. Therefore inductive learning including tree growing algorithm and size optimisation and has used [5]. The concept of the family product can be segmented in a limited number of common components to fit customisation [6,7]. Product customisation is base on a pre-defined structure model. Therefore, mass customisation can cluster common functions, materials and appearances whereas the nature of personalisation does not support the family product. Customisation has consistently used tolerance in design and manufacturing by defining acceptable limitations. This restriction reflects consequence boundaries on customer's desires. From a manufacturing perspective, tolerance related studies are focusing on assembling product components. A precise tolerance has recognised as a competitive advantage in product design. However, with the emerging data-oriented models, applying the degree of personalisation becomes possible [8]. Most research such as mass customisation in paratransit service is limited to the product family, customer segmentation and predefined products [9]. Emerging Industry 4.0 technology is a game changer. For instance, the Rapid Manufacturing (RM), also known as Additive Manufacturing (AM) has a great perspective to advance mass customisation. Industries have utilised product configuration and 3D printing farms to carry out the transition from mass production to mass customisation [10]. Manufacturing for the similarity of production has improved by enhanced module partition scheme [11]. Negotiation theory for product configuration between customers and manufacturers has considered a wider range of product modification. However, product cost, manufacturing capabilities, and resource availability along with unclear customer requirements have resulted in a series of predefined options [12]. For leveraging the success, front-end configuration (e.g. customers and salespersons) transferred to the personalised back-end configuration [13,14]. The virtual prototyping has considered through integrated manufacturing. So the extra cost of the iterative process and further modification has reduced in the evaluation, analysis, design, planning, and manufacturing [15]. Most personalisation studies have applied flexible CAD design to reuse resources by modifying a pre-defined interface [16]. The ability to modify products at low cost and short time is a serious constraint in manufacturing capabilities [17]. To achieve personalisation in scale, the concept of Service Oriented Manufacturing (SOM) and Cloud Manufacturing (CMfg) have facilitated on-demand manufacturing services [18]. Moving from technology-oriented to service-oriented is a challenge in CMfg [19]. Industry 4.0 has enabled smart factories through real-time sensing capabilities and seamless integration of different sensors [20,21]. The value of eco-system that Industry 4.0 offered has never existed for mass personalisation. The goal is to make personalisation as much close to mass production efficiency. Affordability of personalisation is a serious challenge due to dependency and complexity [22]. Unique design has a direct impact on mass personalisation. Personalised product design considered as a bottleneck and the most resource consuming phase in mass personalisation [23]. Almost all studies have contributed to personalisation in cyberspace or physical products co-design process [24,25]. Affordable change in physical attributes is the major challenge that can be reduced by the integration of CAD files over CMfg [26,27]. The degree of personalisation is a tradeoff between customers' needs and manufacturing cost. Closing the gap between the unit price of a tailored product and unite cost is a target to achieve [28]. As per Industry 4.0 roadmap, the ability to make affordable and highest tailored products within an adequate lead-time claimed. In the Industry 4.0 era, both SOM and CMfg are the new manufacturing paradigms, which provide on-demand manufacturing services such as personalisation [4]. By enabling Industry 4.0 technologies, emerging mass personalisation paradigm is more feasible than ever.

3. Definition and Concepts

Mass customisation has met an acceptable cost for different category of products with predefined and limited product configuration. On the other hand, personalisation has fulfilled extreme personalisation but associated with a significant increase in cost. Offering affordable and tailored products based on individuals' requirements has a crucial position in customer satisfaction. In mass customisation, customers have the opportunity to choose from affordable but limited to a range of clustered products. Due to close market competition, industries are keen to move from customer segmentation to mass personalisation business model. This situation shows that business sectors have entered an era of personalisation at scale. Although mass customisation has presented clustered products with near mass production efficiency, mass personalisation is the ultimate goal. Mass personalisation is a customer oriented, and data-driven concept with a combination of distinct features and the value proposition of mass production. Industry 4.0 is offering suitable technologies to meet affordable and highest degree of personalisation. Although customer's engagement in design has identified as a best practice, affordability of products has affected in the co-design process. Extra delivery time and cost in product personalisation is highly dependent on the individual's interaction with things consist of products, services and people. Unlike mass personalisation, customers only engage after products have made available in mass customisation. In personalisation, customers are involved in product development through the entire product development life cycle including design and test. So, one of the fundamental differences between personalisation and mass personalisation is customer engagement in the UX and co-design process. Mass personalisation is dependent on historical data, although mass personalisation has advantages to both personalisation and mass customisation. Mass customisation required subsequent product development while mass personalisation required an Agile approach due to unclear and continuous requirement changes [29,30]. The trade-off between efficiency and the highest degree of personalisation remained the ultimate goal for third party providers and customers. While customisation assumes fixed and pre-defined configuration, personalisation implies possible changes in the basic design and features. Mass personalisation depends on enterprise logistics service, so not only the personalised product but also personalised supply chain management (SCM) should be considered [31]. The adaptability and unpredictability of product designs become essential for mass personalisation. Therefore, due to the mass personalisation complexity, the orchestration of required services with personalisation as a service (Pa^2S) bring significant value to stakeholders. The degree of mass personalisation is a range between mass production and unique characteristics. The higher DoMP often requires more resources and effort to achieve. So analysing DoMP for meeting customer satisfaction is a crucial success for business sectors. Finally, yet importantly, mass customisation is product oriented while mass personalisation is extremely customer and data-oriented model. So mass personalisation goes beyond configuration-to-order, pre-defined customer and product segmentation within scaled service oriented personalisation.

4. Methodology

The request for a wide range of products never stop. Often the demand of customers would increase with the increase of personalisation degree within a cost close to mass production.

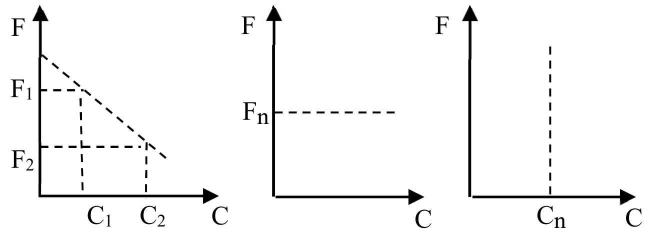

Fig. 1. (a) Demand decline; (b) Constant demand (c) Constant cost.

However, with the rise in price, the need for tailored products could decrease [32]. Fig. 1 shows a liner request for a customer's demand F (d) = a – b C which C indicates the affordability of personalised products. The degree of mass personalisation assumed DoMP = d = Ps/Ts, which Ps represents the number of personalised services that provisioned and Ts represents all the services used to make a product. So, Ts ≥ Ps and d ϵ [0, 1].

$$d = \begin{cases} 0 & \text{Highest degree of mass production.} \\ Ps/Ts & \text{Degree of mass personalisation.} \\ 1 & \text{Highest degree of mass personalisation.} \end{cases} \quad (1)$$

The degree of mass personalisation is a complex and often nonlinear function consist of different technical and business parameters which could change in demand or cost as the two main entities. Fig 2 shows an affordable personalised product, in which the customer's demand will increase if personalisation increases. So, o as the DoMP factor has introduced as

$$o = f(DoMP) = DoMP / (1-DoMP) = d / (1-d) \quad (2)$$

By referring to the demand function, the personalisation demand function to serve a customer shown as:

$$F = a - bC + oF_0 = a - bC + \frac{d}{1-d} F_0 \quad (3)$$

In demand, function bC represents the decreased demand due to cost, and $(d/(1-d))\,F_0$ represents the decreased demand due to the additional cost associated with personalisation.

The cost of a unite product in mass production is the cost of mass production (M_1) and the personalisation cost (oM_2), as shown in the following:

$$MP = M_1 + oM_2 = M_1 + \frac{d}{1-d} M_2 \quad (4)$$

By replacing DoMP factor (o) ,t he equation shows that M_2, the increased cost due to personalisation has affected by the degree of personalisation factor. The o is a supplementary to the M_1, the mass production unit cost. The extra cost is due to the mutual interaction between providers and a customer, so if the customer's part namedαconsequently the other is 1-α. As a result, the product cost for customer/user U has a proportion of M_1 and M_2, respectively.

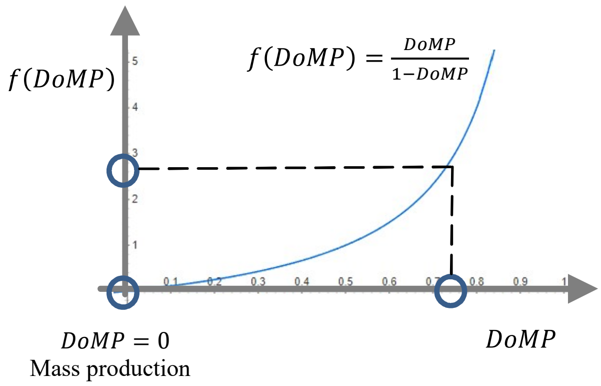

Fig. 2. The relationship between product demand and affordability.

Cost of mass production includes marginal profit M_1 (1+v) and $\beta\tau$C as the benefit of personalisation service. Therefore, P expressed as in 4.

$$C = M_1(1+v) + \alpha.o.M_2$$
$$C = M_1(1+v) + \alpha.\frac{d}{1-d}.M_2 \qquad (5)$$

Replaced (4) into the demand function, the customer's demand as follows:

$$o = \frac{d}{1-d}$$
$$F = a - bC + oF_0$$
$$F = a - b[M_1(1+v) + \alpha.o.M_2] + o.F_0$$
$$F = a - b\left[M_1(1+v) + \alpha\frac{d}{1-d}M_2\right] + \frac{d}{1-d}F_0 \qquad (6)$$

To investigate the relationship between customer's demand and personalisation, the differential equation of customer's demand in mass personalisation using personalisation as a service (Pa^2S) versus DoMP factor (o) as follows:

$$F = a - bC + oF_0$$
$$F = oF_0 + a - b[M_1(1+v) + \alpha M_2 o]$$
$$\frac{\partial F}{\partial o} = F_0 - bM_2\alpha$$
$$\theta = F_0 - bM_2\alpha \qquad (7)$$

This equation represents the degree of customer's demand with the degree of personalisation, which named θ to describe the rate of customer demand due to change of DoMP in service-oriented mass personalisation. The customer demand for the product is subject to price and DoMP; the customer demand will increase with the increase of personalisation. However, it will decrease with the price increase.

- F0: Represents increased demand by increased DoMP.
- $bM_2\alpha$: Represents increased demand by increased price.

Table 1. The Degree of Mass Personalisation Notations.

Notations	Description	Notations	Description
d	The Degree of Mass Personalisation.	MP	The total cost of a personalised product.
o	DoMP factor.	M_1	The unite cost in mass production.
θ	The rate of requirements' change.	M_2	The increased cost due to mass personalisation.
v	Marginal profit ratio in mass production.	C	The unit cost of mass personalisation in Pa^2S
α	The percentage of personalisation cost raised by customer's demand	F	The demand of customers in Pa^2S.
a	Customer's demand possibility.	F_0	The extra demand due to personalisation.
b	The affordable price of a product.	F_1	The customer's demand for mass production.

This equation is consist of affordable price for a customer, the unit for the increased cost, and increase the cost of personalisation by the customer. This model is going to be expanded by adding affordability into the formula because the cost of the product does not always reflect the customer's financial position in regard to a tailored product.

5. Experiment and Discussion

With the market value of wearables on the rise, there is a developing market for the mass personalisation of smart wearables due to individual's requirements. With the increase in urban density and pollution, the demand for air pollution masks is increasing too. The value of smart and personalised mask motivated companies to not only ensure the best air filtering fit to each customer but also a unique appearance to suit the personality of each wearer. Fig 3 shows how personalisation in scale works for unique products in the context of Industry 4.0. This experiment has sidestepped the co-design process for gathering requirements. Instead, a service has called to provide Cloud-enabled Customer Profile (CCP) to make seamless and affordable personalisation. Using CCP has given an opportunity to identify the preferred product's functionalities and appearances (F&A) by calling Microsoft A.I (Artificial Intelligence) as a service. These two layers have a vital position in mass personalisation due to efficiency and affordability in scale. The outcome of the most likely preferred F&A has offered to a customer through an agile product development process. The most and valued added part of mass personalisation is smart personalisation design where an original CAD file would change based on individual attributes such as size, product material and colour. Before getting involved in personalisation, a customer will have a clear view of product affordability by using DoMP, so that decision making along with possible optimisation (not in the scope of this study) brings significant value. Customers have the opportunity to visualise a personalised product using Augmented Reality (AR) for a personalised CAD file. The cost of any changes would be minimal due to the incremental and iterative process. Additive Manufacturing (A.M) or 3D printing farms has considered after the AR layer to make the final product. This layer has utilised CMfg for the most affordable and available resources by using DoMP in the backend. There are factors involved in personalising design by using Creo software, visualising by using Vuforia software, and manufacturing by using 3D printing all through ThingWorx as an IoT software in this experiment.

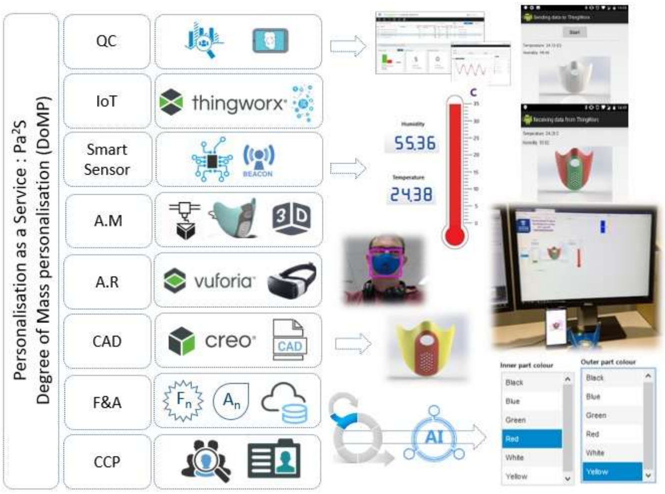

Fig 3. Mass personalisation under Industry 4.0.

This experiment has assumed the mask is a smart product, so the product performance has measured, and relevant information including humidity and temperature of breathing Air have presented on a mobile app as well as a web page monitoring system. Using IoT enabled mask provides an indicator for measuring the quality of a personalised product.

6. Challenges and Future Perspectives

High customer demand and industrial completion have encouraged almost all business sectors to move beyond mass production. However, targeting individuals' requirements has severe concerns that researchers are willing to resolve by using cutting-edge Industry 4.0 technologies. Mass personalisation as an industry strategy has grabbed attention after mass production, mass customisation and personalisation manufacturing models. However, mass personalisation as the next manufacturing paradigm faced significant challenges due to the lack of transparency before initiating a personalised product. The demand has turned to mass personalisation as people expected affordable and tailored products to meet unique requirements. So customers not only have the desire to personalised functionalities and appearances, they would like to have the most affordable one. A big challenge is to define the highest acceptable personalisation with the lowest cost in the complex mass personalisation paradigm. The future perspective is to consider all factors involved in tailored functionalities and appearances under Industry 4.0. The expectation is to utilise both Cloud and CMfg to get the best out of shared resources while customers would like to have real-time pre-evaluation decision-making to specify the level of personalisation.

Furthermore, personalisation as a service (Pa^2S) should adopt agile as the most suitable product development for mass personalisation. Having said that DoMP is not showing how to make the affordable personalised product but bring significant value to decision making. Finally, yet importantly, a comprehensive optimisation is not in place.

7. Conclusion

Mass personalisation has arisen as a manufacturing paradigm in the fourth industrial revolution and leans towards affordable personalisation close to mass production. This study has compared mass customisation, personalisation and mass personalisation manufacturing paradigms. The ultimate goal is to meet the highest customer satisfaction through mass personalisation. However, a balance between the highest level of personalisation and affordability has highlighted as the main question. This study has proposed DoMP and provides visibility to customers for decision making. The proposed DoMP act as a real-time indicator for both customers and providers in a mutual direction. This model shows that mass personalisation has comprised of parameters related to both mass production and personalisation as a service (Pa^2S). The relationship between the three main factors including the rate of requirement change, affordability, and demand have discussed. The impact of increased demand by increased DoMP and price has formulated between zero for mass production and one for the highest degree of personalisation. Above all, a conclusion can be obtained that the demand of customers would increase with the increase of personalisation degree and affordability. In this paper, DoMP facilitates the integration of core personalisation factors and proposed suitable Industry 4.0 technologies for mass personalisation as an emerging manufacturing paradigm. While this study has proposed a model for the degree of mass personalisation, expected future work on two significant aspects. 1) Expanding DoMP to cover key personalisation factors in suitable Industry 4.0 technologies. 2) Optimising DoMP to offer best options rather than facilitating the decision making. In the former case, an advanced DoMP model can be used in personalisation as a service. The effort in every applied Industry 4.0 technology including but not limited to IoT, AR, AM and Cloud could be considered in a backend mass personalisation process. So, customers would have real-time information to check the total cost involved in the DoMP to making a decision. In the latter case, the application of both Deep Learning (DL) and Machine Learning (ML) technologies could create most value personalised product for the product price.

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