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Differential pricing integrated with multi-product, multi-machine, multi-worker cost function for resource service providers in cloud manufacturing

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ABSTRACT

Cloud manufacturing (CMfg) platform offers an open marketplace, where a Resource Service Provider (RSP) can benefit from Price Discrimination (PD) in return for specific services. However, the literature focused mainly on operator-based pricing and overlooked RSP pricing control. Therefore, this study formulates a profit function in which revenue is enhanced by adjusting prices according to customer types, while cost accounting is done by resource allocation based Material Flow Cost Accounting (MFCA) because MFCA provides a comprehensive guideline towards waste minimization. The proposed model is formulated into MINLP problem with multiple factors such as; part types, batch size, part routes, machine types, energy consumption, worker types and material handling cost as well as price sensitive customer behaviour and demand. Further, ANOVA is applied for factors analysis. The results suggests that customer types and demand are positively correlated, while parts, machines, and worker types are negatively correlated with profit. The model is also compared with reference price effect and fixed pricing strategy. Results validate that to benefit from diverse customer behaviour in CMfg, PD along with optimal resource allocation provides an effective solution for profit maximization. Model is also compared with reference price effect and fixed pricing strategy to validate its effectiveness.

1. Introduction

Cloud Manufacturing (CMfg) is a novel manufacturing paradigm that provides a collaborative environment for the ubiquitous transformation of resources into manufacturing services [1]. The platform offers open access to Resource Service Providers (RSPs) to sell their manufacturing services, and to customers to buy services based on a pay-as-you-go model. Thus, removing the barrier to enter or leave the platform results in diverse customer types and service providers on the platform. For RSPs, geographic, time, and type dispersion of customers can provide space in price adjustment while the same dispersion of manufacturers can provide an advantage in operating costs and uniqueness in services. Based on this premise, Price Discrimination (PD) and cost control of services can promise higher revenues for RSPs in CMfg.

However, the literature on CMfg is focused on operator-based pricing strategies while considering fixed prices for RSPs, thus it impedes revenue maximization of RSPs. This impediment can be overcome by varying prices of the same product/services for different customers. This is termed as Price Discrimination (PD) and is in practice in many service industries such as airlines and hotels [2, 3]. In this paper, the potential of PD is utilized for RSP in CMfg.

On the other hand, Cost Accounting (CA) of service providence is critical to estimate true variable costs to control costs. With the advancement in variety and complexity, traditional CA methods are becoming inadequate to provide true cost estimates [4]. A comprehensive CA method that incorporates energy costs, material costs, labor costs, and other system costs can provide more realistic estimates and thus better control costs. In this work, the CA of resource allocation for service providence is adopted from the performance measures of Material Flow Cost Accounting (MFCA). MFCA/ISO-14051 is a comprehensive tool for CA of manufacturing systems to meet the contemporary requirements of sustainable and eco-economic manufacturing. It monitors the flow and stock of resources in a production system and categorizes the economic value of a product into the material, energy, and system costs. Application of MFCA has been reported in manufacturing as well as service sectors, where the results have shown environmental as well as economic improvements in the systems [5]

Based on the above discussion, a multi-criteria Mixed-Integer Non-Linear Programming (MINLP) model is formulated to minimize the service providence cost adopted from MFCA and to maximize profit using PD. The model comprises multiple factors such as energy, material, labor, and material handling costs of service providence as well as price-sensitive demand. Furthermore, to assess the profit margin of RSP under reference price in CMfg, a comparative study of DP with reference effect and Fixed Pricing (FP) is also provided.

The remaining paper is organized in a way that a summary of the literature is provided in Section 2 with identified research gap. Section 3 includes mathematical modeling of the proposed model. Section 4 includes numerical problem and ANOVA study with results. Section 5 concludes the current work with future research recommendations.

2. Literature Review

CMfg was introduced in 2009, which enabled on-demand use of manufacturing resources and capabilities in the form of services in a collaborative cloud environment [6]. Various authors have summarized the architecture, characteristics, and challenges of CMfg in their work [7-9]. In terms of stakeholders, CMfg system mainly comprises (i) manufacturers (RSPs) who own manufacturing resources and sell their services on cloud (ii) cloud platform operator or third party who is responsible for delivering services according to the customer requirements, and (iii) customers or service demanders who purchase the services. Because CMfg is still in its early adoption phase [10, 11] and few manufacturers are aware of this term [12, 13]; therefore, early adopters among RSPs have the advantage of a monopolistic market environment in CMfg. Due to this non-saturation in the cloud market, there is variation in services offered by different RSPs based on quality, reliability, capability, time or geography. The literature supports this argument by providing research on Quality of Service (QoS) in CMfg based on these factors. Examples include the work of Tao, et al. [14] who developed a service composition model for enterprise in CMfg based on the cost of service, reliability and time duration. Liu, et al. [15] proposed a RS sharing model in CMfg based on QoS that includes utilization of resources, satisfaction, and geographical locations. Akbaripour, et al. [16] also considered geographical location while estimating their QoS metric for time, cost, and quality in service composition. Wang, et al. [17] considered customer satisfaction and service quality while, Wang, et al. [18] considered the uncertainty factor of faulty equipment to improve the QoS in CMfg. Therefore, these differentiated QoS can provide leverage to RSP by adjusting prices independently.

2.1 Literature on Price Discrimination For Revenue Generation

Generally, monopolists strive to charge the highest prices where demand is inelastic, i.e., where charging high prices leads to an increase in revenue without a substantial decrease in demand and vice versa [19]. The differentiation in prices is mostly motivated by customer buying behavior. Particularly, the monopolist can readily identify discrete market segments in PD; for example, airlines use PD on the basis of customer types such as early or late buyers [20, 21], because some customers are willing to pay more for the same product or service. Also restaurants are using PD model for their revenue management [22]. Layson [23] mentioned conditions by which PD opens up new markets that cannot be served under uniform pricing. The literature provides extensive research on advantages of PD in the service sector such as hotels [24], pharmaceutical industry [25], internet services [26], fashion apparel industry [27], as well as in the manufacturing sector under monopolistic competition [28, 29]. Interesting research on market segmentation for PD based on information sharing is proposed by Jain, et al. [30] for a multi-echelon supply chain model. While focusing on customer segmentation for PD, Kurt Christensen [31] worked on defining the customer value for competitive advantage. Based on their findings, market segmentation can be done by carefully analyzing the information extracted from customer buying behavior. Sato [32] introduced PD for the customers who can postpone their purchasing decisions to minimize the potential risks.

2.2. Price Discrimination in Cloud Manufacturing

Geographical dispersion, time variation, customization in preferences and/or price sensitivity creates a defined boundary between market segments of customers on CMfg. Thus, the application of PD is a promising strategy on a cloud platform. Moreover, the concept of CMfg leads to the servitization of manufacturing, i.e., Manufacturing-as-a-Service (MaaS); therefore, this work provides an initiative to embed PD from the perspective of a RSP in CMfg akin to its wide application in the service sector. Although, there is a vast literature on PD in cloud-based systems such as the work of [33-35], however, these models are based on the pricing of servers or software resources such as bandwidth, CPU time, memory, and storage. Recently, Peng, et al. [36] have proposed a Dynamic pricing model for CMfg supply chain. They highlighted the effect of the customer population that includes bargainers and price-takers on price selection. However, the cost was considered constant and the price differentiation was initiated and decided by the cloud operator rather than the RSP. Also, Zhang, et al. [37] proposed collaborative pricing model for cloud RSP for dynamic environment. Despite the remarkable contribution of mentioned works on pricing in the cloud environment, PD from the perspective of an RSP in CMfg has not been given due attention. This paper proposes a PD model for RSP in CMfg to fill the gap.

2.3. Literature on Cost Accounting for Profit Maximization

Price adjustment is one part of the profit equation. Equally important is the Cost Accounting (CA) of products and services. Along with PD, RSPs can maximize their profit by considering optimal resource allocation and efficient CA of service providence in order to estimate true variable costs. Manufacturing resources in CMfg form the basis for market competition [38]. More resources lead to more market share; therefore, the optimal utilization of resources is key to profit generation. In doing so, efficient cost accounting of the manufacturing process helps to minimize the waste of resources [39, 40]. The effects of comprehensive CA in the automotive industry were studied by Jasinski, et al. [41]. Cooper and Kaplan [42] studied the effect of CA methodology on product costs. Another aspect of CA was introduced as Activity-based CA or resource CA, which provided a more comprehensive aspect of financial benefits in the manufacturing sector [43]. Giri, et al. [44] proposed a joint pricing and inventory management problem which included the CA of substitutable products. Mutha, et al. [45] proposed profit maximization function of multiple-use cycle products using the CA methodology However, traditional CA methods are inadequate to identify the waste of resources and thus include waste in product costs, whereas in CMfg the services offered by manufacturers are their resources. Also, literature depict that inefficient utilization of resources can lead to loss of market share and reduced profit margins [11]. To address this perspective, ISO 14051/MFCA is adopted in the proposed work.

2.4. Introduction to Material Flow Cost Accounting

In 2011, the International Organization for Standardization published ISO 14051/MFCA for CA of production systems based on the consumption of resources. MFCA is defined as an ecology-oriented CA instrument that quantifies energy and material consumption in monetary units along with system costs for material handling and labor consumption. Improved transparency of material flows and associated costs facilitates the visualization of resources being consumed and identify the inefficiencies at every stage of production [46]. This motivates decision-makers to enhance resource efficiencies and reduce potential waste caused by inefficient methods or processes. The significance of MFCA as compared to the traditional CA methods is provided by Sygulla, et al. [47] and Kokubu [48]. Its application has been widely used in many production and service organizations for effective CA of systems [49-52]. However, so far MFCA is used as curative strategy for the reduction of waste and improvement of flow, while its use as preventative strategy at the modeling and design stage is rare. Whilst the use of MFCA for preventive cost modeling integrated with pricing for profit maximization is rarest if any.

In the past research, only pricing was considered as an effective marketing tool to maximize the firms' profit; whereas, integrated pricing and CA problems have become the main category of revenue management approaches with the advancement in decision-making strategies [53].

Keeping in mind the gaps in recent the aforementioned literature, this work proposes the following to address those gaps.

- Although there are PD models for manufacturers in general, only with either a single product or single line or with a constant cost. While in this paper, multi-product, multi-machine, multi-worker and variable costs are considered.
- It considered PD strategy for RSP in CMfg which has not been given due attention so far and based on the literature, there is potential for RSP profit maximization for monopolistic competition.
- The application of MFCA has so far been considered in CA on/in existing processes as a curative measure, while in this work, we have adopted MFCA parameters in system modeling for service providence as a preventive measure.
- The proposed work fills the literature gap of an integrated PD and resource allocation model for an RSP in CMfg.

3. Methodology

3.1. Problem Description

Considering the characteristics of CMfg RSP, a flexible job-shop environment with multi-machine types, multi-worker types, and multi-parts types with multi-routes are considered. Keeping in mind the advantages of group technology for variable demand and product mix, machine grouping is used. Workers are considered multi-skilled and grouped into levels based on their ability to operate different sets of machine/s. Resources are allocated to minimize the cost of service providence. To do so, CA of service providence is done by adopting costs of MFCA that are (i) Energy Cost, (ii) Material Cost, and (iii) System Cost.

Akin to other e-business platforms, the infancy stage of CMfg market is more monopolistic and as the market saturates, it tends to be more competitive which affects customers' preferences with respect to price from price takers to bargainers. Besides, due to geographical disparity and job shop environment, services demanded are sometimes unique because of the unique combination of one's resources, geology, expertise, while other times those could be not so unique. For unique services customers are more of price takers and for common services they are more of bargainers. Moreover, there is no restriction on an RSP to serves local customers as well as through the cloud platform. While, there is no barrier for customers to enter or exit the cloud platform, which exhibits diversity in customer types such as bargainers or negotiators or price-takers. Mostly, price takers are not much price sensitive and they avail themselves of the services on the first go, while the bargainers are more price-sensitive and they take time to analyze market price, while negotiators lie in between. The objective of RSP is to maximize the profit by determining prices for different purchasing behaviors of customers. The schematics of DP integrated with MFCA- inspired cost is presented in Fig. 1. The detailed formulation is explained in the next section.

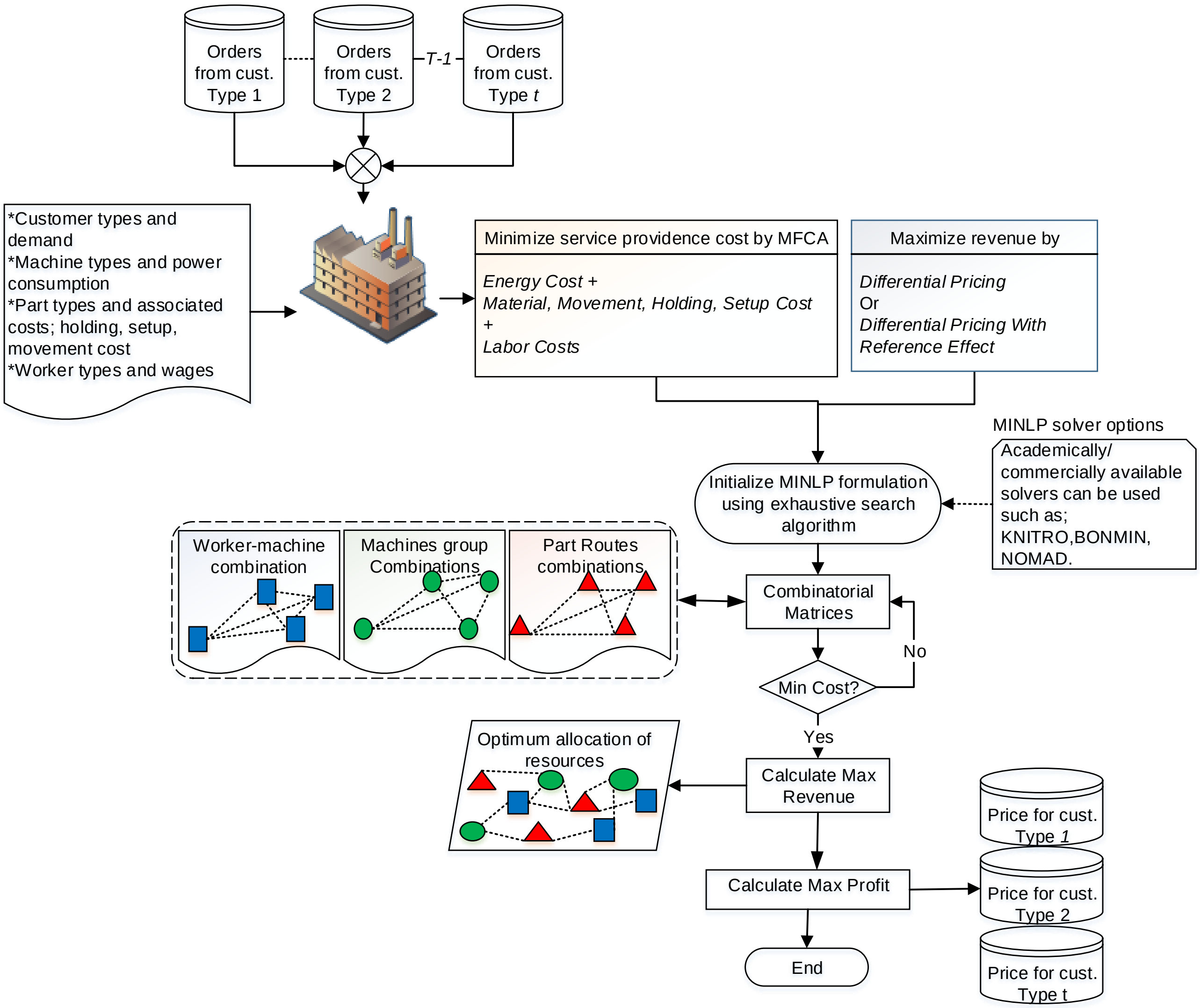

Fig. 1. Schematics of DP integrated with MFCA inspired costs

3.2. Problem Formulation

In this section, the notations used in modeling are described in alphabetical order under each category. Afterward, the mathematical model is presented along with assumptions and constraints.

3.2.1. Indices

G = Number of groups (g = 1, 2… G).

Rx = Set of routes for part x (rx = 1, 2… Rx).

W = Worker skill levels (w = 1, 2… W).

X = Types of parts in a service (x=1, 2…X).

Y = Types of machines (y = 1, 2…Y).

T = Types of customers (t = 1, 2…T).

3.2.2. Parameters

D = Demand.

LB_g = Minimum group size.

$MCap_y$ = Time capacity of machine type y (min).

N_{yg} = Number of machines y assigned to group g.

M_y = Make to part power of machine y (hp/min).

P_t = Price of service providence per unit customer type t.

UB_g = Maximum group size.

$WCap_w$ = Time capacity of worker type w (min).

α = Demand constant .

β_t = Price sensitivity coefficient of customer type t.

μ_{wyr} = Processing time of part x on machine y in route r (min).

3.2.3. Cost parameters

$ECost$ = Per unit cost of power consumption (/min).

HC_x = Holding cost of part x.

MoveCost_x = Movement cost of part x (/batch).

SC_x = Setup cost of part *x*.

$WrkrCost_x$ = Cost of worker type '*w*' worker (/min).

3.2.4. Decision Variables

G_{xry} = 1, if part *x* is processed on machine *y* in route r; = 0, otherwise .

Q_{xrg} = 1, if part *x* is processed in group g in route r ; = 0 , otherwise.

ρ_{xywg}= 1, if part *x* is processed on machine y with worker *w* in group *g*; =0, otherwise

3.3. Cost Accounting of Resource Allocation

Cost accounting of resource allocation process is done using costs considered by MFCA: (i) Energy Cost; (ii) Material Cost; and (iii) System Cost. Energy Cost (EC) is minimized by selecting optimal routes of parts, which accounts for low energy consumption machines. This formulation is presented in Eq. 1.

$$EC = ECost \sum_{rx=1}^{R_x}\sum_{y=1}^{Y}\sum_{x=1}^{X} M_y \mu_{xyr} G_{xyr} D \tag{1}$$

Here, one can think that the cost of lost energy due to inefficient process planning is not incorporated. This aspect is under the scope of product design and process planning; whereas current research is about operational modeling and production planning for resource allocation. Therefore, energy-efficient routing is selected for each part using the above equation to minimize the energy consumption cost. The same applies to the cost of lost material during machining, which is under the scope of process planning and product design.

Because MFCA traces the flow as well as a stock of material in a system [54], minimizing work-in-process would, therefore, minimize the material waste, and in turn the negative material cost. Zhao, et al. [55] provided a simulation study for selecting an optimal batch size to minimize the scrapped overdue stocks during the application of MFCA. This aspect is integrated with Material Movement Cost (MC), which is highlighted in MFCA as a part of system costs. The problem is formulated in Eq. 2 in which the total movement of batches is minimized. Eq. 2 accounts for the number of moves of batches between machine groups. As the moves are routing dependent, they are therefore minimized by selecting optimal routing.

$$MC = \sum_{x=1}^{X} \text{MoveCost}_x \sqrt{\frac{\text{HC}_x D}{2\text{SC}_x}} \left(\sum_{g=1}^{G}\sum_{rx=1}^{Rx} Q_{xrg} - 1 \right) \tag{2}$$

Another parameter of MFCA in system costs is Labor Cost (LC). Current globalization in the manufacturing industry has increased the competitive pressure on organizations to increase productivity while minimizing costs. One way of doing so is labor management. In CMfg, the geographical diversity in resources also demands cost-effective management of labor to keep up with the competitors whose geographical regions have cheap labor. Therefore, a skill-based labor assignment is done to minimize labor cost. This formulation is presented in Eq. 3.

$$LC = \sum_{g=1}^{G}\sum_{rx=1}^{Rx}\sum_{w=1}^{W}\sum_{y=1}^{Y}\sum_{x=1}^{X} \text{WrkrCost}_w \rho_{xywg} \mu_{xyr} D \tag{3}$$

The overall cost function for the resource allocation process is given in Eq. 4.

$$\min C = \text{ECost} \sum_{y=1}^{Y}\sum_{x=1}^{X}\sum_{rx=1}^{Rx} M_y \mu_{xry} G_{xry} D + \sum_{x=1}^{X} \text{MoveCost}_x \sqrt{\frac{\text{HC}_x D}{2\text{SC}_x}} \left(\sum_{g=1}^{G}\sum_{rx=1}^{Rx} Q_{xrg} - 1 \right) + \sum_{g=1}^{G}\sum_{rx=1}^{Rx}\sum_{w=1}^{W}\sum_{y=1}^{Y}\sum_{x=1}^{X} \text{WrkrCost}_w \rho_{xywg} \mu_{xry} D \tag{4}$$

3.4. Revenue Maximization of Resource Service Provider

Eq. 5 maximizes the revenue ($\Re$) of a RSP that uses PD for customer type *t* [56]. The price-sensitive demand behavior of customers is represented by a linear demand function (α-$\beta_t P_t$). Change in value of $\boldsymbol{\beta}$ interprets the behavior of different types of customers; for instance, the bargainers, who are more price-sensitive, have a high value of $\boldsymbol{\beta}$ while the price-takers, who are less sensitive to price changes and adopt the initially given prices, have a low value of $\boldsymbol{\beta}$**.**

$$\max \Re = \sum_{t=1}^{T} (P_t(\alpha - \beta_t p_t) \tag{5}$$

3.5. Objective Functions

3.5.1. Differential Pricing Strategy

Combining Eq. 4 and 5 formulates the objective function of profit (Z) maximization that uses DP and CA, summarized in Eq. 6.

$$\max Z = \sum_{t=1}^{T} (P_t - C)(\alpha - \beta_t P_t) \tag{6}$$

The first derivative of Eq. 6 gives the optimal value of price for each customer type *t* as shown in Eq. 7.

$$P_t^* = \frac{\alpha}{2\beta} + \frac{C}{2} \tag{7}$$

In order to get a feasible solution of proposed model, some practical constraints are defined.

$$\sum_{g=1}^{G} N_{yg} = 1 \quad \forall \text{g} \tag{8}$$

$$LB_g \le \sum_{y=1}^{Y} N_{yg} \le UB_g \quad \forall g \tag{9}$$

$$\sum_{g=1}^{G} Q_{xrg} \ge 1 \quad \forall x \tag{10}$$

$$\sum_{g=1}^{G}\sum_{w=1}^{W}\sum_{y=1}^{Y}\sum_{x=1}^{X} D\mu_{xyr}\rho_{xywg} \le \sum_{w=1}^{W} WCap \tag{11}$$

$$\sum_{y=1}^{Y}\sum_{x=1}^{X} D\mu_{xyr}G_{xyr} \le \sum_{y=1}^{Y} MCap \tag{12}$$

Constraint (8) restricts duplication of machines in groups. Constraint (9) represents the group size limit. Constraint (10) represents the movement of parts within machine groups. Constraints (11) and (12) show workers and machines capacity constraints. Workload assigned to each machine on each route must be within the capacity of machines.

3.5.2. Differential Pricing with Reference Effect

Adaption level theory [57] explained reference price as the response of customers to the current price by comparing it with past price exposures. Keeping in mind the price sensitive behavior of customers, we also investigate the reference price effect on customer buying behavior. The hypothesis is that price takers or early buyers do not rely on bargaining price; therefore, their behavior would not be much affected by reference price. However, the bargainers are more inclined towards previous price patterns [58]; therefore, their demand may vary with reference price. Eq. 13 defines reference price effect in demand, where γ shows the reference effect of previous price P_{t-1} adopted from [59] and **C** is service providence cost, defined in Eq. 4.

$$\max Z_2 = \sum_{t=1}^{T} (P_t - C)(\alpha - \beta_t P_t + \gamma(P_{t-1})) \tag{13}$$

s.t; $P_0 = 0, \gamma = 0.5, t = (1,2,3)$ (14)

3.6. Solution Method

From Eq. 5, 6 and 13, the revenue function and profit functions are linear with linear and mixed-integer constraints. However, the square root term in move cost function in Eq. 4 renders the objective functions as an MINLP problem. For practical purposes, commercially and/or academically available solvers for MINLP, such as BONMIN, KNITRO, NOMAD, can also be used [60]. For research purposes, an exhaustive search algorithm is used to obtain optimal solution provided the problem sizes. The algorithm is run on Windows 10, a 64-bit operating system with 4 GB RAM, using MATLAB R2018a. The range of solution run time is from 3.22 seconds for a small problem size of seven machines, three parts and two workers, to 34.41 seconds for nine machines, 15 parts and four workers. Pseudo code for the exhaustive search algorithm for the proposed scenario is provided below.

Initialize

1. RC← Combinations of part routings
2. MG← Combinations of machines in groups.
3. WC← Combinations of workers with machines
4. T← Customer types
5. for i←1 to Length [RC]
6. for j← 1 to Length [MG]
7. for k←1to Length [WC]
8. Do Calculate Cost← min(Energy_Cost(i)+Movement_Cost(i,j)+Labor_cost(i,k))
9. end for all
10. return i*, j*, k*← min(Cost)
11. for t=1←T
12. Do *Calculate Revenue**←max(P(t)*D(t))
13. return *P(t)**← max(*Revenue*)
14. Do Calculate Profit (Z) ← (P(t)*- Cost) *D(t)
15. end for

4. Case Study

To demonstrate the behavior of the above dynamic models, numerical case studies were conducted using randomly generated values for the parameters. Data related to RSP's resources are given in Table 1. It includes 7 machines with their make-to-part power, three product types, four types of skilled workers and their corresponding wages. The lower limit of group size is defined as 2. Production time is taken as 26 days with machines operating at/on two shifts and worker time capacity is 7.5 hours per shift.

Table 1

Machine-Worker-Part data for Case Study 1

Machines	Make-to-part power of machine (kW/minute)	Worker type	Worker wage/shift (unit currency)	Part (operation time(minutes))					
				P1		P2		P3	
1	12	1	130	2	-	-	-	4	-
2	7	3	180	2	3	-	2	2	3
		4	200						
3	4	2	150	-	4	4	2	-	4
		4	200						
4	6	1	130	3	-	3	4	3	-
5	12	2	150	-	5	3	2	2	-
		4	200						
6	6	3	180	4	-	-	-	2	-
		4	200						
7	8	2	150	-	4	3	4	-	3
		4	200						
Holding cost				4		3		5	
Setup cost				20		30		25	
Movement cost				1.2		1.2		1.2	

Data related to customer types with corresponding α value is given in Table 2.

Table 2

Customer types with corresponding α value

Customer type (t)	Price-takers	Negotiators	Bargainers
Price Sensitivity Coefficient(β)	1.5	2	2.5

4.1. Results and Discussion

To compare the results, the problem is solved using (i) differential pricing, (ii) differential pricing with reference effect, and (iii) fixed pricing for which $P_1=P_2=P_3$. The results are presented in Table 3, which shows profit achieved with each strategy.

Table 3

Profit Comparison of different pricing strategies

Customer type	Profit with Differential Pricing	Profit with Differential Pricing w/ Reference Effect	Profit with Fixed Pricing
Price takers	1356.6	1356.6	1356.6
Negotiators	945.3	1745.8	806.4
Bargainers	700.6	1302.0	256.1
Total profit	3002.5	4404.5	2419.2

When the results of profit generation using DP are compared with a fixed pricing strategy in which the RSP offers the same price to all customers, the total profit of RSP is decreased from 3002.5 units to 2419.165 units, while the profit of DP with reference effect is greater than DP strategy 4404.5 units. This is in line with the literature of reference pricing, which states that the profit increases with reference price effect [61]. However, the use of reference pricing is not always promising because in this strategy, the manufacturer sets the price just below the market price to gain a competitive edge, and in doing so, the profit margin can be reduced [62]. However, the reference effect in a monopolistic environment is profitable while keeping the quality of the product the same.

Service providence cost of RSP is minimized with the optimal grouping of resources. Resource configuration and optimal batch size are presented in Fig. 2.

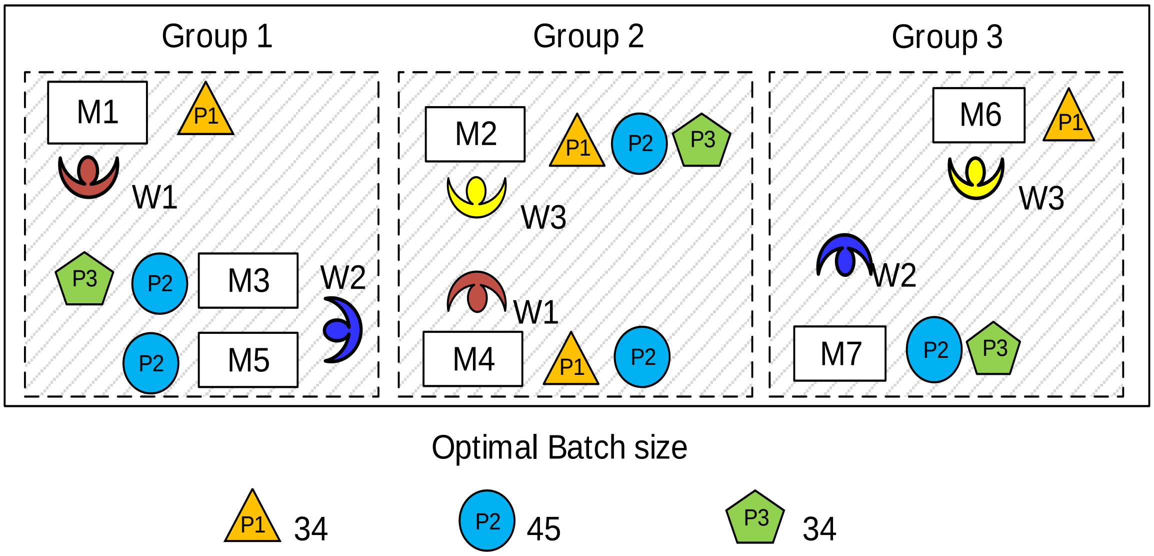

Fig. 2. Schematic representation of optimal resource grouping and batch size of parts to minimize the cost of service providence

4.1.1. Effect of prices on demand

Because the customer demand is price sensitive, the effect of different pricing strategy on demand is therefore also analyzed and presented in Fig. 3.

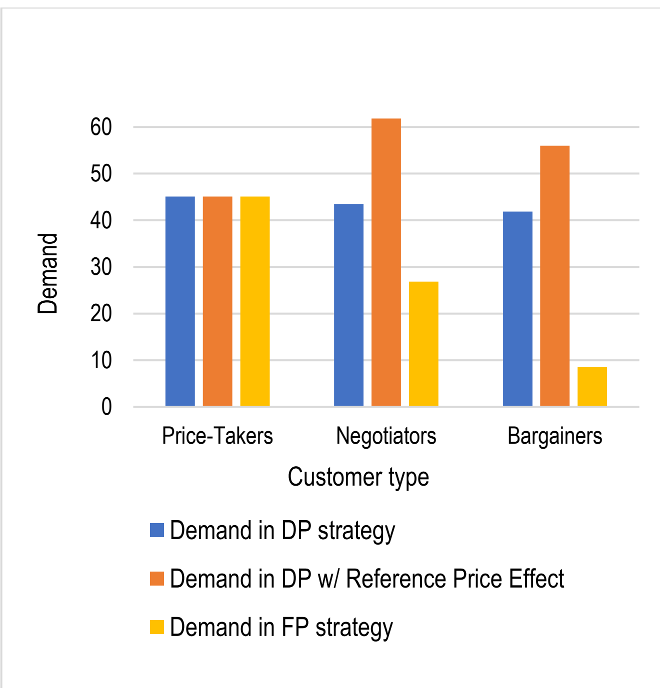

Fig. 3. Comparison of Demand for customer types under different pricing strategies

Fig. 3 shows that demand decreases more drastically in FP strategy as compared to DP for each customer type. As it is clear from the graph that price controls the demand; therefore, demand can be adjusted using the DP strategy to generate profit from limited capacity. Moreover, the effect of reference price on demand of the price-sensitive customer is also high as compared to the DP strategy. This can be justified by the fact that the reference effect creates a physiological impact on the customer when one compares the current price with the previous price and finds it lower than before, the demand increases. Overall, the demand for customer types decreases from bargainers to price-takers, because the latter is more price-sensitive; therefore, the impact of reference price is less than compared to earlier. To further investigate the effects of customers' behavior, demand, and resources' types, a 2k factorial design is used in the next section.

4.2. Factorial Design for Cost-Profit tradeoff

To analyze the Cost-Price-Profit tradeoff, a 2k Factorial design is applied. Each variable is defined at two levels (high and low). The selected variables and their values at a low and high level are given in Table 4.

Table 4

Actors and levels for 2k Factorial Design

Factor	Customer types (A)	Resource Groups (B)	Part types (C)	Machine types (D)	Worker types (E)	Demand (F)
Levels	(2, 3)	(2,3)	(7,15)	(5,9)	(2,4)	(100,500)

64 sample problems were generated using Design Expert 10.0.6. In order to analyze the factorial combination for maximizing profit with minimum cost, results are arranged in ascending order of their profit

from DP in Fig. 4. From the figure one can observe three regions in the graph along horizontal axis from left to right as: (i) low cost-low profit region; (ii) high cost-medium profit region; and (iii) medium cost-high profit region.

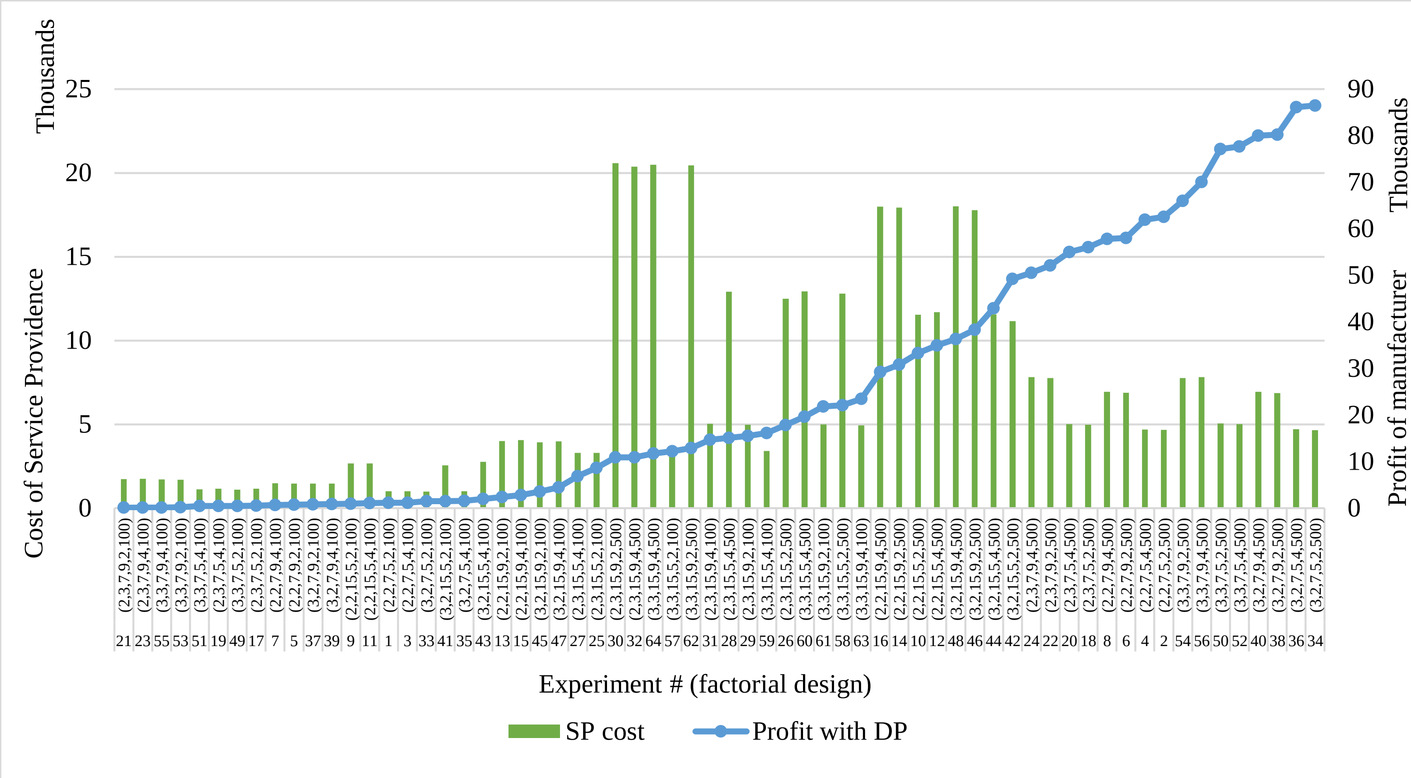

Fig. 4. Cost-Profit trade-off for sample problems

Clearly, there are some factors in the middle of the graph that impact the cost but not profit with the same ratio and vice versa for the third region of the graph. To further analyze all the factors and their interaction in Fig. 4, ANOVA is applied in the next section to identify the significant ones.

4.2.1. Factors Analysis using ANOVA

Significant factors and their interactions are provided in Table 5, using Half-Normal Plot. Table 5 shows that Customer types and Machine types have the highest contribution in profit generation. The effect of the individual factor is provided in Fig. 5 where each alphabet letter represents a factor as explained in Table 4. The graph shows that Factors A (Customer type) and F (Demand) have a positive relationship with the profit while C (Part types), D (Machine Types) and E (Worker types) have a negative relation with profit. Therefore, RSP can increase its profit by carefully forecasting the customer demand behavior on different prices using cloud data and by adjusting the resource availability on the cloud according to the demand.

Table 4

ANOVA results

Factor	Sum of Squares	Degree of freedom	Mean Square	F Value	% Contributio
Model	4.764E+010	13	3.665E+009	660.64	
A-Customer type	2.826E+010	1	2.826E+010	5094.45	59.98
C-Part types in a service	6.874E+007	1	6.874E+007	12.39	0.14
D-Machine Types	4.457E+009	1	4.457E+009	803.45	9.30
E-Worker types	3.437E+008	1	3.437E+008	61.96	0.72
F-Demand	9.996E+008	1	9.996E+008	180.21	2.09
AC	2.961E+008	1	2.961E+008	53.39	0.62
AD	9.716E+009	1	9.716E+009	1751.57	20.28
AE	1.777E+009	1	1.777E+009	320.30	3.71

AF	5.435E+008	1	5.435E+008	97.98	1.13
DF	1.221E+008	1	1.221E+008	22.02	0.25
ADE	7.024E+008	1	7.024E+008	126.62	1.47
ADF	3.546E+008	1	3.546E+008	63.93	0.74
Residual	2.773E+008	50	5.547E+006		
Corrected Total	4.792E+010	63			

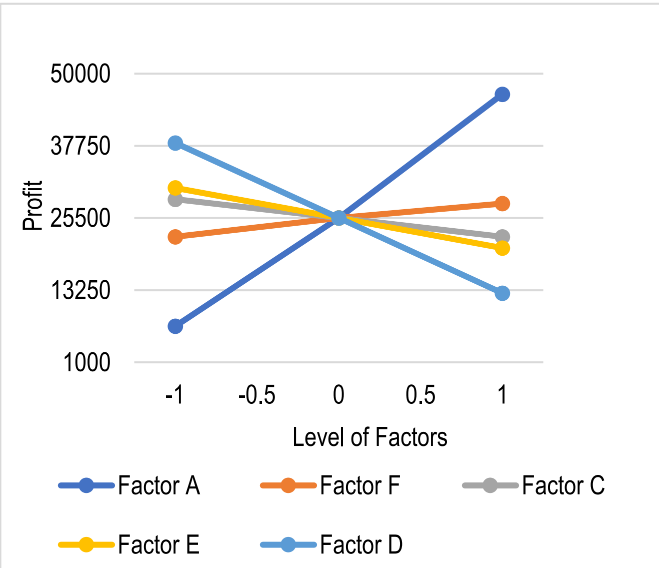

Fig. 5: Factor effect on profit

The positive relation of Factor F (demand) with profit justifies the low cost-low profit region of Fig. 4; low total revenue due to low demand and hence low-profit margin. The negative relation of Factor C (Part types) with profit justifies the high cost-medium profit region of Fig. 4 with high part variety, increasing the production cost; therefore, profit is comparatively low in this region. The medium cost-high profit region of Fig. 4 can be justified with low part variety. Although the demand is high, the interaction effect of CF (Part variety and demand) is not significant according to ANOVA. Thus, the Medium variety production model can be profitable for RSP in the CMfg platform. This area represents high demand, more resource utilization, and high customer classification that contribute towards high profit.

5. Conclusion, Significance, and Recommendations

CMfg has introduced servitization in the manufacturing industry where geographically dispersed RSPs provide their manufacturing services to other manufacturers or customers. While this transformation is in an early adoption stage(s), the market for RSPs is more monopolistic and will tend towards competitive with saturation. A profit maximization strategy for RSP in CMfg with integrated pricing and resource allocation model is presented. PD is done for dynamic customer behavior in CMfg based on their willingness to pay. To minimize cost, MFCA inspired CA of resource allocation is formulated by considering energy, material, labor, and material movement costs. For comparison purposes, the reference effect on price is also incorporated to analyze its effect on customer buying behavior. The results of the proposed models are analyzed using numerical studies, which depict the effectiveness of DP strategies over FP. Results highlighted that FP reduced the profit margin because setting an equal price for all market segments reduced the profit margin from the customers who are less price-sensitive. At the same time, the reference price increased the profit for the same customer sensitivity. Furthermore, critical factors are identified using ANOVA, which shows that customer segmentation and demand for service had positively affected the profit, while machine types, labor, and parts variety had a negative effect. Adjusting machines' availability with customer demand also affected the profit. Using this information, the profit of RSPs can be adjusted according to market demand and in-hand resources.

The significance of the work is for the manufacturers, who can now exercise some play over prices and may find it attractive to adopt CMfg. Another significance of the work is sustainability and waste-conscious CA that takes inspiration from MFCA. Furthermore, as the data becomes ubiquitous, the applicability of the model is not limited to specific demand patterns and customer behaviours. Another significance of the work is the identification of factors, negatively and positively correlated with the price that has a direct bearing on profit.

As not all the resources of a manufacturer may be utilized from CMfg platform alone, therefore incorporating local (non CMfg) customer behavior would add more profit. In the future, the proposed work could be extended by integrating third-degree PD with second degree PD (price variation with order quantity), because the price-sensitive customer behavior has a direct impact on demand quantity. To further develop the concept, the overall pricing mechanism can be improved by applying MFCA over the CMfg supply chain.

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