International Conference on Mechanical, Industrial and Energy Engineering 2018
23-24December, 2018, Khulna, BANGLADESH

ICMIEE18-156

Proposition of Additive Manufacturing Technique for Artificial Bone Implantations and Its Feasibility Assessment via Cost Analysis

Nusrath Zahan[1], M.Fakhrul Islam Jony[2], and Khairun Nahar[3]*
[1]Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh
[2]Lira Group of Industries, Gulshan 2, Dhaka, Bangladesh
[3*]Assistant Professor, Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

ABSTRACT

Osteoarthritis (OA) of the hip is the most common joint disease in elderly people and associated with significant physical disability. Pain relief is a primary treatment of hip OA. When the patient with hip OA has failed medical treatment modalities and remains in pain, the patient should be referred for hip replacement surgery in which the damaged surfaces of the joint is removed and replaced with a set of artificial ball-and-socket implants. In this research, a proposition for Additive Manufacturing (AM) is advocated to produce the bone implant to enhance the customer satisfaction along with minimization of costs. AM is fundamentally different because it creates product by successive deposits of material instead of using removal or forming processes. Because of this difference, the cost and operational characteristics are distinct from traditional manufacturing. For this reason, additive manufacturing is placed in an end-to-end supply chain context and a stochastic optimization model is proposed to help a manufacturer decide when AM is best for them. Two business models are also proposed based on the additive manufacturing technology: manufacturing dominant model and retailer dominant model to investigate the financial viability of these models.

Keywords: Biomedical implants; Additive manufacturing; Supply chain; Cost analysis; Stochastic programming model; Business model innovation.

1. Introduction

The burden of musculoskeletal conditions is rising all over the world; Osteoarthritis (OA) is one of them which cause pain in the limb. In a healthy person, the bones joints are cushioned by cartilage, allowing for unconstrained movement of the joint. With OA, the cartilage breaks down and as the cartilage deteriorates, bone rubs on bone, resulting in pain and reduced mobility. Pain relief is a primary goal in treating of these patients. In the critical stage of OA, the medical treatment fails and patients remain in pain with limitations of physical function in daily life. This patients would be helped best with a surgery in which an artificial bone implant is replaced to match their anatomy. For this bone implantation surgery most of the patients either go to abroad or the manufacturing of the bone implants is held in other country and they are purchased with a high transportation cost. In both cases the whole process of surgery is very costly and time consuming. For this reason we need a convenient process that can be proven as a very supportive way of enhancing customer satisfaction by minimizing the cost of artificial bone implant.

In this case, Additive Manufacturing can be proposed as an effective way. AM is a collection of modern technologies which creates products by the addition of layers in the third dimension instead of subtracting or forming material, which are used in other manufacturing methods. Huang et al (2013) discussed that additive manufacturing can produce a final product in one build, there is limited exposure to hazardous conditions and there is little hazardous waste [7]. According to Tuck and Hague (2006) and Walter et al. (2004), by being a very strong enabler of product customization, 3D printing can have remarkable impacts on downstream sections of the supply chain, such as production and distribution [9]. A study on 3d printing and its future, Koff & Gustafson (2014) said that the most inspiring use of 3D printing is in the healthcare industry, where 3D printing has the potential to save lives or dramatically improve them. It is designed to print bone joint and tissue structures using data from medical scans, such as CT or MRI [12]. Jia, F., Wang, X., Mustafee, N., Hao, L. (2015) showed the difference between two business model for the chocolate industry for both standard & customized product. 3D chocolate printing provides the technology for manufacturing chocolates layer-by-layer, thus offering customers enhanced product value and personalized consumption experience [4].This research work discusses the additive manufacturing in perspective of Bangladesh for artificial hip bone implantation surgery. By introducing additive manufacturing this research reveals the possibilities of increasing capacity, reduction of cost and time in hip replacement surgery.

2. Mathematical Statements

In this section a stochastic cost model is developed to quantify the supply-chain level costs associated with the production of artificial hip implants using both traditional manufacturing and Additive Manufacturing (AM) technologies and investigated the economic feasibility of using these technologies to fabricate hip implants in Bangladesh. This model mainly focused on modeling

* Corresponding author. Tel.: +88-01916800200
E-mail addresses: khairun.nahar@ipe.ruet.ac.bd, shapla05.ipe@gmail.com

system-level costs such as inventory, transportation the effects of product lead time on the overall transportation costs.

2.1 Model formulation: Let's consider a scenario where a set of customers (C) need a set of products (I) in a set of time periods (T). The products (I) can be manufactured by a set of traditional manufacturing plants (P) and a set of Additive manufacturing plants (A). Both traditional and Additive manufacturing plants receive product materials from a group of suppliers (S). There are costs associated with supplier selection, product transportation, facilities opening and operating, inventory management, and production. Our approach here is to design an effective supply chain considering possible use of traditional manufacturing system or Additive manufacturing systems. We have developed a MILP model to get optimal configuration of a supply chain variant.

Sets:
a: Set of Additive manufacturing plants; *c*: Set of customers; *i*: Set of products; *p*: Set of traditional manufacturing plants; *s*: Set of suppliers; *t*: Set of time periods; *w*: Set of warehouse.

General Parameters:
i. $demand_{it}$: demand of product
ii. $mfg\_capacity_{pit}$: TM plant capacity
iii. $mfg\_var\_cost_{pit}$: TM variable cost
iv. $mfg\_oper\_cost_{pit}$: TM plant operation cost
v. $mfg\_open\_cost_{p}$: TM opening cost

Distribution Parameters:
i. $wh\_var\_cost_{wit}$: warehouse variable cost
ii. $wh\_oper\_cost_{wit}$: warehouse operating cost
iii. $wh\_open\_cost_{w}$: warehouse opening cost

Supply Parameters:
i. $supplier\_capacity_{sit}$: Supplier capacity
ii. $tsupplier\_cost_{sit}$: supplier unit cost for TM plant
iii. $amsupplier\_cost_{sit}$: supplier unit cost for AM plant

Additive manufacturing Parameters:
i. $am\_mach\_hours_{at}$: AM machine capacity
ii. $am\_cap\_usage_{it(w)}$: hours to build 1 product
iii. $am\_oper\_cost_{ait}$: AM plants operating cost
iv. $am\_mach\_purchcost_{ait}$: AM machine purchase cost
v. $am\_mat\_cost_{t(w)}$: AM materials cost per KG
vi. $am\_mat\_usage_{it}$: AM materials usage per product
vii. $am\_open\_cost_{a}$: AM location opening cost
viii. $am\_var\_cost_{ait}$: AM variable cost

Transportation Parameters:
i. $am\_trans\_cost_{acit}$: unit transportation cost from AM location to customer
ii. $ib\_trans\_cost_{pwit}$: unit transportation cost from TM plant to warehouse
iii. $ob\_trans\_cost_{pwit}$: unit transportation cost from warehouse to customer
iv. $tsupply\_trans\_cost_{spit}$: unit transportation cost from supplier to TM plant
v. $amsupply\_trans\_cost_{sait}$: unit transportation cost from supplier to AM plant

Inventory Parameters:
i. aii_{a}: AM plant's starting inventory
ii. $inventory\_hold\_cost_{i}$: holding cost
iii. pii_{p}: TM plant's starting inventory
iv. wii_{w}: warehouse starting inventory
v. M: a sufficiently large number

Integer Decision Variables:
i. aii_{ait}: AM starting inventory
ii. aei_{ait}: AM ending inventory
iii. pii_{pit}: TM starting inventory
iv. pei_{pit}: TM ending inventory
v. wii_{wit}: warehouse starting inventory
vi. wei_{wit}: warehouse ending inventory
vii. fsp_{spit}: supply of materials for product i from supplier s to manufacturer p at time t
viii. fsa_{sait}: supply of materials for product i from supplier s to AM plant *a* at time t
ix. fpw_{pwit}: supply of product i from TM plant p to warehouse w at time t
x. fwc_{wcit}: supply of product i from warehouse w to customer c at time t
xi. fac_{acit}: supply of product i from AM plant a to customer *c* at time t
xii. $am\_oper\_machines_{ait}$: number of AM machines operating at time t to produce i
xiii. $am\_production_{ait}$: no. of product i is produced by AM plant a at time
xiv. *p_production (P,I,T):* no. of product i is produced by TM plant p at time t

Binary Decision Variables:
i. y_{wcit} =1 if customer c gets supply of product i from warehouse w at time t
ii. z_{acit} =1 if customer c gets supply of product i from Additive manufacturing plant a at time t
iii. x_{wcit} =1 if warehouse w is open for product i at time t
iv. xa_{ait} =1 if Additive manufacturing plant a is open for product i at time t
v. xp_{pit} =1 if traditional manufacturing plant p is open for product i at time t
vi. sp_{spit} =1 if supplier s supplies material for product i to plant p at time t
vii. sa_{sait} =1 if supplier s supply material for product i to AM plant a at time t

The formulation is the following:
Minimize

$$\sum_{s \in S} \sum_{p \in P} \sum_{i \in I} \sum_{t \in T} tsupply\_trans\_cost_{spit} * fsp_{spit} + \sum_{s \in S} \sum_{a \in A} \sum_{i \in I} \sum_{t \in T} amsupply\_trans\_cost_{sait} * fsa_{sait} + \sum_{p \in P} \sum_{w \in W} \sum_{i \in I} \sum_{t \in T} ib\_trans\_cost_{pwit} * fpw_{pwit} + \sum_{w \in W} \sum_{c \in C} \sum_{i \in I} \sum_{t \in T} ob\_trans\_cost_{wcit} * fwc_{wcit} + \sum_{a \in A} \sum_{c \in C} \sum_{i \in I} \sum_{t \in T} am\_trans\_cost_{acit} * fac_{acit} + \sum_{w \in W} \sum_{i \in I} \sum_{t \in T} wei_{wit} * inventory\_hold\_cost_{i} + \sum_{p \in P} \sum_{i \in I} \sum_{t \in T} pei_{pit} * inventory\_hold\_cost_{i} + \sum_{a \in A} \sum_{i \in I} \sum_{t \in T} aei_{pit} * inventory\_hold\_cost_{i} + \sum_{a \in A} \sum_{i \in I} \sum_{t \in T} am\_var\_cost_{ait} * am\_production_{ait} + \sum_{p \in P} \sum_{i \in I} \sum_{t \in T} mfg\_var\_cost_{pit} * p\_production_{pit} + \sum_{p \in P} \sum_{i \in I} \sum_{t \in T} xp_{pit} * mfg\_open\_cost_{p} + \sum_{a \in A} \sum_{i \in I} \sum_{t \in T} xa_{ait} * am\_open\_cost_{a} +$$

$\sum_{w \in W} \sum_{i \in I} \sum_{t \in T} xw_{wit} * wh\_open\_cos_w +$
$\sum_{s \in S} \sum_{p \in P} \sum_{i \in I} \sum_{t \in T} tsupplier\_cost_{sit} * sps_{pit} +$
$\sum_{s \in S} \sum_{a \in A} \sum_{i \in I} \sum_{t \in T} amsupply\_cost_{sit} * sa_{sait} +$
$\sum_{p \in P} \sum_{i \in I} \sum_{t \in T} mfg\_oper\_cost_{pit} * xp_{pit} +$
$\sum_{a \in A} \sum_{i \in I} \sum_{t \in T} am\_oper\_cost_{ait} * xa_{ait} +$
$\sum_{w \in W} \sum_{i \in I} \sum_{t \in T} wh\_oper\_cost_{wit} * xw_{wit}$ .....(1)

The objective function is to minimize total supply chain cost.

Subject to…

$\sum_{w \in W} \sum_{i \in I} y_{wcit} + \sum_{a \in A} \sum_{i \in I} z_{acit} = 1$ ..(2)

Every customer is served by either warehouse or AM plant

$xw_{wit} \geq y_{wcit},$ ...(3)

If a customer is assigned to a warehouse then that warehouse must be up

$xa_{ait} \geq z_{acit},$ ...(4)

If a customer is assigned to a AM plant then that plant must be up

$fwc_{wcit} = y_{wcit} * demand_{cit}$ ....(5)

Amount of flow from warehouse w to customer c for product i at time t

$fac_{acit} = z_{acit} * demand_{cit}$ ...… (6)

Amount of flow from Additive manufacturing plant a to customer c for product I at time t

$wii_{wit} + \sum_{p \epsilon P} fpw_{pwit} = wei_{wit} + \sum_{c \epsilon C} fwc_{wcit}$.....(7)

Flow balance for warehouse

$wii_{wit} = wii_w,$ .....… (8)

At time t = 1 every warehouse has a given inventory

$wii_{wit} = wei_{wi(t-1)},$ …(9)

At time t > 1 initial inventory is the ending inventory of t-1 time period

$pii_{pit} + \sum_{s \epsilon S} fsp_{spit} = pei_{pit} + \sum_{w \epsilon W} fpw_{pwit}$ .. (10)

Flow balance for traditional plant

$pii_{wit} = pii_p,$ ...….. (11)

At time t =1 every manufacturing plant has a given inventory

$pii_{wit} = pei_{pi(t-1)},$ ……(12)

At time t > 1 initial inventory is equivalent to the ending inventory of t-1 time period

$aii_{pit} + \sum_{s \epsilon S} fsa_{sait} = aei_{ait} + \sum_{c \epsilon C} fac_{acit},$ .... (13)

Flow balance for Additive manufacturing

$aii_{ait} = aii_a,$ ...….. (14)

at time = 1 AM plant has a given inventory

$aii_{ait} = aei_{ai(t-1)},$ ……(15)

At time t > 1 initial inventory of AM plant is equivalent to the ending inventory of t-1 time period

$pii_{pit} + \sum_{w \epsilon W} fpw_{pwit} - pei_{pit} \leq mfg\_capacity_{pit},$ … (16)

Capacity constraint for traditional factory

$aii_{pit} + \sum_{c \epsilon C} fac_{acit} - aei_{ait} \leq am\_mach\_hours_{ait} * am\_oper\_machines_{ait} / am\_cap\_usage_{it},$ … (17)

Capacity constraint for Additive manufacturing plant

$\sum_{a \epsilon A} fsa_{sait} + \sum_{p \epsilon P} fsa_{spit} \leq supplier\_capacity_{sit},$ ….(18)

Capacity constraint for supplier

$am\_production_{ait} = aii_{ait} + \sum_{c \epsilon C} fac_{acit} - aei_{ait}$…. (19)

Total production at AM plant at time t

$p\_production_{pit} = pii_{ait} + \sum_{w \epsilon W} fpw_{pwit} - pei_{ait}$…… (20)

Total production at traditional plant at time t

$p\_production_{pit} \leq xp_{pit} * M$ …. (21)

If there is a production from a traditional plant than that traditional plant must be up

$am\_production_{pit} \leq xa_{pit} * M$ ....(22)

If there is a production from a AM plant than that AM plant must be up $fsa_{sait} \leq sa_{sait} * M,$ …………(23)

If there is a flow from a supplier to a AM plant then that supplier-plant relation is on

$fsp_{spit} \leq sp_{spit} * M,$ …… (24)

If there is a flow from a supplier to a traditional plant then that supplier-plant relation is on

$am\_oper\_machines_{ait} = am\_production_{ait} / am\_mach\_hours_{ait},$ … (25)

Number of AM machines required to run at time t in AM plant.

2.2Numerical Illustration

In this section, data gathered from the professionals and 6Axis technologies are applied to the above model and solved by using the GAMS software to find the best possible solution. The input data and result of the decision variables are given in Table 1 and Table 2. Finally the total supply chain costs of both models are presented in Table 3.

Table 1 Input Parameters

General Parameters	**Unit**	**AM Parameters**	**Unit**
$demand_{it}$	238	$am\_mach\_hours_{at}$	2400
	364	$am\_cap\_usage_{it(w)}$	1
	201	$am\_oper\_cost_{ait}$	34000 BDT
	169	$am\_mach\_purchcost_{ait}$	35000000 BDT
$mfg\_capacity_{pit}$	1000	$am\_mat\_cost_{t(w}$	37100
$mfg\_var\_cost_{pit}$	63615 BDT	$am\_mat\_usage_{it}$	1.3kg
$mfg\_oper\_cost_{pit}$	354000 BDT	$am\_open\_cost_a$	11500 BDT
$mfg\_open\_cost_p$	108300000 BDT	$am\_var\_cost_{ait}$	48200 BDT
Distribution Parameters		**Supply Parameters**	
$wh\_var\_cost_{wit}$	2670 BDT	Supplier capacity	12000
			10500
			10000
$wh\_oper\_cost_{wit}$	10000 BDT		9000
$wh\_open\_cost_w$	640000 BDT	Supplier unit cost for TM plant	19824
			15310
Transportation Parameters			14500
			10450
$am\_trans\_cost_{acit}$	0.00	$ob\_trans\_cost_{pwit}$	40000 BDT
$ib\_trans\_cost_{pwit}$	50 BDT		
$inventory\_hold\_cost_i$	100 BDT		

*Source: 6Axis Technologies.Unimed &Unihealth Pharmaceuticals ltd

Table 2 Solution of Integer Decision variables

Results	Unit		
	Period 1	Period 2	Period 3
aii_{ait}	0	0	0
aei_{ait}	0	0	0
pii_{pit}	1200	1200	0
pei_{pit}	1200	0	0
wii_{wi}	500	219	1074
wei_{wit}	219	1074	727
fsp_{spit}	5400	5675	5400
fsa_{sait}	345	448	451
fpw_{pwit}	0	1200	0
fac_{acit}	69	92	78
	112	127	125
	57	71	73
	43	55	71
$am\_oper\_machines_{ait}$	1		
$am\_production_{ait}$	281	345	347
$p\_production$	0	2400	0

Table 3 MIP solution of total supply chain cost

TM Plant	AM Plant
283291370.00	88879156.00

From table 2 and table 3 it can be seen that both the starting and ending inventory of AM plant remains zero because this plant anticipates only by the customer demand. On the other hand TM plant maintains the production schedule by forecasting demand based on different specification of hip prosthesis. Another advantage of AM plant is that there is no need of warehouse in this plant, which also reduces the total supply chain cost. Finally the additive manufacturing technology maintains the quicker response with respect to customer demand compared to the TM plant.So, based on the above analysis it can be said that Additive manufacturing is economically feasible for the production of artificial hip implant as the total supply chain cost of AM plant is lower than that of TM plant.

3. Bio Implant Business Model

Additive manufacturing technology represents a revolutionary manufacturing approach which can engage consumers to create and produce hip bone locally and share their digitized product design and innovation globally. But robust business models are necessary for ensuring the economic sustainability of additive manufacturing of hip prosthesis which will account the profitability aspects of the supply chain constituents, viz., the manufacturer and the hospital, and the utility derived by the end user. Towards this, we present two business models 1) the manufacturer-dominant model 2) the distributor dominant model where the manufacturer of artificial bone adopts this technology, with production taking place at the manufacturer's plants and manufacturers sell the product to the local distributers (hospitals).The latter scenario is that of a distributer adopting this technology with the final production taking at hospital. The purpose of this section is to outline two business models for additive manufacturing of hip prosthesis and make comparison between them in terms of the earned profit.

3.1 Manufacturer-dominant business model

The manufacturer dominant model is the first supply-centric business model innovation. Here the manufacturer is responsible for the customized manufacturing of hip bone. The conventional supply chain channel is complemented by processes pertaining to the production of customized hip bone, wherein, (a) hospitals order personalized product through the distribution center, (b) the orders are communicated to the manufacturer, (c) the hip bone manufactured using process materials and additive manufacturing machine, (d) the manufacturer transports the customized product back to the distribution center, and (e) the hospitals collects the products from the distribution- center (Fig. 1).

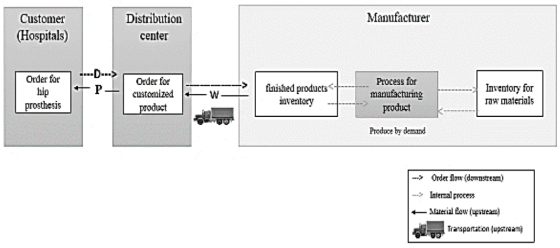

Fig. 1: Manufacturer-Dominant supply chain model

The proposed supply-chain structure also includes the customer–manufacturer channel which facilitates communication between the hospital and the manufacturer with the objective of fulfilling customer demand. In the customer–manufacturer channel the role of the distribution center is made redundant. Fig. 1 shows the customer demand for products (D) the corresponding prices are P. Finally the variables W refer to the price the distributor has to pay to the manufacturer for the products.

3.2 Distributor-dominant business model

In this supply chain model, the product is created using the additive manufacturing technology by the distributor. The hip bone is manufactured using processed materials which have to be ordered from the supplier. Compared to the previous model wherein the manufacturer has processes pertaining to production, in second model this is incorporated with distributors' processes. The variables shown in Fig. 2 are similar to those in Fig. 1 since in both scenarios customer demand exists for product (D) however, unlike the previous scenario wherein the manufacturer fulfilled the order, in this model the customer receives the product from the distributor. The price for D is P. For both models 1 and 2 there is no inventory subsequent to the process for manufacturing product since this is a make-to-order strategy. Finally, for both models presented, there exists an inventory for raw material at distribution center since it is make-to-order.

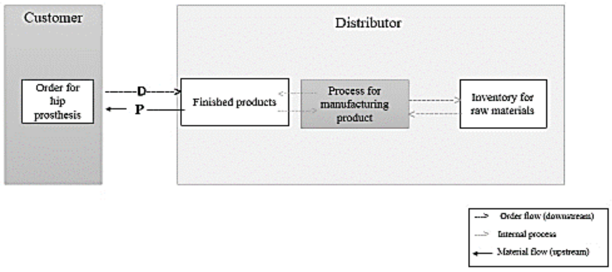

Figure 2: Distributor-Dominant supply chain model

Brief Study of business models:
The additive manufacturing technology will enable manufacturers and distributor to produce hip prosthesis based on customer preferences; this is especially true for the manufacture of product with shape-customization. In additive manufacturing technology, production does not commence until an order is received with clear customer preference information. For the purpose of comparison, we have implemented real data collected from the local market and hospitals for all the business models outlined in the previous section. These are discussed next.

Parameter definitions:
In this section we present the modeling parameters which have been used in the subsequent equations to calculate inventory and the profitability functions pertaining to the supply-chain centric business models.
(T) Operating cycle, *(k)* order times, (*n)* produce times, (*Q)* economic order quantity, *(D)*demand for hip prosthesis, (*P)* price of product, (*W)*purchase price of distributor, ($C_{h)}$ inventory holding cost, ($C_{o)}$ cost of transportation each time, ($C_{p)}$ operating cost each time, ($C_{u)}$ production cost of product,($C_{s)}$ ordering cost

Business model 1: manufacturer-dominant supply chain
Additive manufacturing of hip bone by the manufacturer decreases the inventory cost of the distributor. In the manufacturer-dominant model, the distributor only bears the inventory costs for finished products. In this part we analyze the profit of supply chain under manufacturer-dominant model. The finished products sales of the distributor will, to a certain extent, be affected by the sale of products. In this model the distributor's profit function is:

$$DP_1 = \frac{(p-w)D - c_o^d - c_h^d}{T}$$

After the introduction of customized production, the profit of double-channel supply chain under manufacturer-dominant model is:

$$MP_1 = \frac{\sum_1^k (w - c_u^m)Q^m - c_p^m - c_h^m - c_s^m}{T}$$

Business model 2: Distributor-dominant supply chain
Under the distributor-dominant supply chain, the product is manufactured by the distributor. For enabling the on-demand manufacture of customized hip bones using additive manufacturing the distributor has to set up a raw material inventory. As a result of the introduction of raw material inventory, distributor's inventory cost will be higher compared to models 1 but distributors 'transportation cost will be eliminated compared to the previous model. Under the distributor -dominant model the distributor will produce the products and the raw materials will be purchased from supplier for producing hip bones by additive manufacturing process. The profit function is:

$$DP_2 = \frac{(p - c_u^d)D - c_h^d - c_s^d - c_p^d}{T}$$

4. Finding and Analysis
Table 4 represents the required data for the profit analysis of the manufacturer dominant model In this model, as the manufacturer adopt AMtechnology, manufacturer's profits increase comparative to distributor's profit.

Table 4 Data and result for manufacturer dominant model

Distributor	**Cost (BDT)**	**Manufacturer**	**Cost (BDT)**
Price of product,P	93550	Holding cost,$\boldsymbol{c_h^m}$	40
Inventory holding cost,c_h^d	20	Operating cost,$\boldsymbol{c_p^m}$	34000
Transportation cost,c_o^d	40000	Production cost,$\boldsymbol{c_u^m}$	53253
Purchase price of distributor, w	69300	Supply unit cost,$\boldsymbol{c_s^m}$	16439
DP₁	**1946393**	***MP₁***	**1960253**

On the other hand, Table 5 shows the profit of distributor in the model 2. In this case distributor's profit increases significantly in comparison to the first model as distributor adopt additive manufacturing technology.

Table 5 Data and result for distributor dominant model

Distributor	**Cost (BDT)**
Price of product,P	93550
Inventory holding cost,c_h^d	40
Supply unit cost,$\boldsymbol{c_s^d}$	16439
Operating cost,$\boldsymbol{c_p^d}$	34000
Production cost,$\boldsymbol{c_u^m}$	53253
DP₂	**3243590**

From the above analysis, it has been found that, the profit of distributor in distributor dominant model is significantly higher than that in manufacturer dominant model. So it would be economically feasible if the distributor adopts the additive manufacturing technology for the production of artificial hip implant and it is important for the manufacturer to adopt the technology first, otherwise if the distributor adopts the technology first, the manufacturer can be replaced. Finally it can be said that the one who adopts the technology first (whether it is manufacturer or distributor) gain higher profits. And if manufacturer allows distributor to adopt the technology and dominate the products market, then he will be squeezed out of market or disrupted by the additive manufacturing technology.

5. Conclusions

In conclusions it can be said that, we have developed a stochastic optimization model to quantify the supply-chain level costs associated with the production of artificial hip implants and investigated the economic feasibility. Then we have formulated the programming code using GAMS software and the MIP solution of the two models given the result that additive manufacturing would be economically beneficial for the production of artificial hip bone implants. We have also formulated two business models for the production of artificial hip implants considering supply chain constituents and analyzed their profitability functions with the aim of experimenting economic viability of the new additive manufacturing technology enabled business models in artificial bone implantation. The results show that 1) whoever between distributor and manufacturer adopts the AM technology first gain higher profits than the other; 2) Manufacturers risk being left out of market if distributors adopt this technology first successfully and assume a dominant position on the market.

REFERENCES

[1] S. Wang, An analysis of manufacturers' supply and demand uncertainty based on the dynamic customization degree, *Int. J. Prod.* Res. 49 (10), 3023–3043 (2011).

[2] D. S. Thomas, S. W. Gilbert, Costs and effectiveness of Additive manufacturing: A literature review and decision, (2014).

[3] M. Ruffo, C. Tuck, R. Hague, Cost estimation for rapid manufacturing-laser sintering production for low to medium volumes. Proceedings of the Institution of Mechanical Engineers, *Part B: Journal of Engineering Manufacture*, 220, 1417-1427 (2006).

[4] F. Jia., X. Wang, N. Mustafee, L. Hao, Investigating the feasibility of supply chain-centric business models in 3D chocolate printing: A simulation study, Technological, *Forecasting & Social Change*, (2015).

[5] M. Ruffo, C. Tuck, R. Hague, Make or buy analysis for rapid manufacturing, *Rapid Prototyping Journal*, 13, 23-29 (2007).

[6] C. Lindemann, U. Jahnke, M. Moi, R. Koch, Analyzing product life cycle costs for a better understanding of cost drivers in additive manufacturing, *23th Annual International Solid Freeform Fabrication Symposium–An Additive Manufacturing Conference*, Austin Texas USA 6th-8th August (2012).

[7] S. H. Huang, P. Liu, A. Mokasdar, L. Hou, Additive manufacturing and its societal impact: A literature review, *International Journal of Advanced Manufacturing Technology*, 67, 1191-1203 (2013).

[8] D. Y. Golhar, S. Banerjee, An Optimal Ordering Strategy for a Third-Party Managed Supply Chain, *International Journal of Production Research*. Vol. 51, Issue 10, pp. 2969 – 2980(2013).

[9] C. Tuck, R. Hough, Management and implementation of rapid manufacturing,https://doi.org/10.1002/0470033991.ch10, (2006).

[10] Y. He, M. Ye, C. Wang, A method in the design and fabrication of exact-fit customized implant based on sectional medical images and rapid prototyping technology, *The International Journal of Advanced Manufacturing Technology*, 28, 504-508 (2006).

[11] M. A. J. M. Gebler, C. Visser, A global sustainability perspective on 3D printing technologies. Energy Policy, 74, 158-167 (2014).

[12] W. Koff, P. Gustafson, 3D Printing and the future of manufacturing (2014).

Appendix:

Data of monthly enlisted patient of hip (OA) from different hospitals in Bangladesh-

M H → ↓	**LabAid Hospital**	**Pongu Hospital**	**Apollo Hospital**	**United Hospital**
January	20	27	14	13
February	13	29	11	8
March	17	25	15	12
April	19	31	17	10
May	21	28	23	11
June	27	34	18	17
July	23	33	13	14
August	21	32	17	13
September	18	34	19	16
October	25	37	18	19
November	19	30	21	17
December	16	24	15	19
Total	238	364	201	169

Prosthesis Production cost-

Object weight(grams)	1360
Printing Time (Hours)	1
Electricity Tariff (£/Kwh)	0.16
Printer Power (watts)	7000
Filament Cost (£/Kg)	380.56
Printer Purchase((£)	428650
Printer lifetime(years)	25
Daily usage(hours)	8
Repairs Costs%	10
Failure Rate%	2.5
Total Cost((£)	549

Production price is calculated from www.3dprinthq.com/cost/desktop.php

1£=97 BDT**,** So that the total production cost**,** £549=53253 BDT.