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# A Manufacturing System Design for Transtibial Prosthetic with CBDM Process in Perspective of Bangladesh

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*In Bangladesh, the major challenges in producing highly customized products like prosthetics are the fulfillment of the demand in least possible time and cost. This study aims to mitigate these problems associated with the concurrent production system by incorporating Cloud Based Design and Manufacturing (CBDM) which refers to a service-oriented collaborative product design and development model where service consumers are capable of selecting, configuring, and utilizing customized product manufacturing resources and services ranging from computer-aided engineering design software to rapidly reconfigurable shared manufacturing resources. The study includes an overview of the current situation of prosthetic production and the possible benefits and challenges of CBDM implementation in Bangladesh. It also presents a comparison between three production models for transtibial prosthetic in perspective of Bangladesh including traditional, combined and CBDM method depending on production time, capacity and unit product cost. Approximate production time and capacity is determined by simulating each model in ARENA simulation software and unit product cost is calculated by conventional costing method. Analysis of these production models has proven CBDM to be helpful in transtibial prosthetic production when incorporated with the traditional manufacturing process resulting in achieving higher capacity, shortest delivery time and least possible cost which can provide a promising approach to implement CBDM in Bangladesh in the future.*

**Fields of Research:** Management

## 1. Introduction

As a result of globalization, brand new design and manufacturing pursuits are performed in a more and more geographically disbursed atmosphere where enterprises have formed complex and decentralized design collaboration and manufacturing supply chain networks. To participate in collaborative design and manufacturing more easily and efficiently within the allotted and collaborative environment, manufacturing firms have been confronted with tremendous capital bills on establishing, working, and retaining riskless, interoperable, and scalable ICT techniques.

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This present day, the emergence of cloud computing represents a radical exchange in the way in which ICT systems are developed, delivered, managed, and maintained. Similar to ICT sector, product design and manufacturing industries are additionally present process a paradigm shift from traditional design and manufacturing to cloud based design and manufacturing by means of relocating extra core business functions onto cloud platforms.

Cloud Based Design and Manufacturing (CBDM) refers to a service-oriented product development system in which service consumers are able to configure products or services as well as reconfigure manufacturing systems as per rapidly changing customer need. It uses the concept of service model of cloud computing system in order to bring the design and manufacturing process under a single hood. Thus providing better information flow in collaborative design process, rapid scalable manufacturing system, reduce the time and cost of product development in a distributed design and shared manufacturing system with the aid of modern manufacturing technologies.

Bangladesh being one of the emerging country in the ICT and manufacturing sectors in the world has yet to incorporate the functionalities, benefits and services of collaborative design and manufacturing system. While the new technologies and improvement in manufacturing processes around the world has brought radical enhancement in the product development process, Bangladesh is still lagging behind owing to lack of collaborative design, high lead time for the final product, lack of new manufacturing technologies and high cost of additional resources required to increase capacity in traditional manufacturing system. This research works discusses the Cloud Based Design and Manufacturing system in perspective of Bangladesh. By leveraging the functionalities of CBDM system this research reveals the possibilities of increasing capacity, reduction of cost and time in product development in a manufacturing system in Bangladesh can be achieved with the help of latest manufacturing and design technologies.

Lately the development of the growth of competitive market globalization and customer demand diversification have led to the increasing demand of agility, networking, service and socialization of manufacturing. With a specific end goal to understand the objectives of the assembling frameworks, for example, quickest time - to-market, most elevated quality, least cost, best service, cleanest environment, most noteworthy flexibility, and high knowledge should be more best in class and spry to take care of the demand of the client and in the meantime keep up an ease of creation. Yet, in traditional manufacturing, it is unrealistic to accomplish this objective in light of ailing in simultaneousness of assembling, absence of cooperation in the design procedure. In the event of creation of profoundly customized item this issue gets more intense. Similar to this above situation prosthetics for patients is one of the major customized the manufactured product in Bangladesh. With the gradual increasing of empowerment of the disabled people, demand of prosthetics has been increasing ever since. Among them the transtibial prosthetics is the major one and most delivered to the patient. In traditional manufacturing transtibial prosthetics are to be manufactured focusing on the measurement of the residual limb from the patient. Thus it requires high accuracy and expert advice and followed by several traditional methods to produce the socket. Thus a patient has to wait several days in order to receive the prosthetics. Beside due to lack of accuracy further fitting is

needed to the product. Besides due to lack of resource the organizations are also facing problem to fulfill the demand. Also high cost of production, lack of collaboration during the process, lack of implementation of newly invented technologies in this sector has made this highly demanded product hard to obtain for the patient and high time consuming, costly and complex for the manufacturer. As above discussed the design and manufacturing system of prosthetics in Bangladesh is still need to be more collaborative, technologically advanced in order to reduce the cost and time to deliver the prosthetics as well as form a flexible manufacturing system in order to increase its capacity to rapidly meet the demand of the customer.
Nayak et al. (2014), Ishengoma and Mtaho (2014), Wu, Terpenny & Gentzsch (2015) and many other researchers have analyzed about CBDM and the comparative benefits and costs for different developed and developing countries. But they did not accomplish such studies or researches in developing country like Bangladesh. The uniqueness of this study is that it includes the benefits and challenges of CBDM implementation in Bangladesh, and also presents a comparison between three production models for Transtibial prosthetic in perspective of Bangladesh including traditional, combined and CBDM method depending on production time, capacity and unit product cost in which comparison in terms of production time and capacity is a new and promising approach for implementation of CBDM.

This paper arranged as follows- Section 2 presents the literature review to identify the research scope of the concept of 3D printing and CBDM to manufacture transtibial prosthetics in Bangladesh. Section 3 explains Cloud Based Design and Manufacturing (CBDM) methodology. Section 4 illustrates a case study in perspective of Bangladesh to understand the necessity of prosthetics and discusses the problems in fulfilling them. Section 5 deals with formulation of three manufacturing models in order to improve the current manufacturing system of transtibial prosthetics and by incorporating CBDM in different level. Section 6 focuses on evaluation of aforementioned models based on some selected criteria. Section 7 presents the comparative results of the models and section 8 provides conclusion of the paper.

## 2. Literature Review

Cloud based design and manufacturing is a service-oriented networked product development model in which service consumers are enabled of configuring, selecting, and utilizing customized product realization resources and services. Though this concept is new in the design and manufacturing system, several outstanding researches have been performed on development of the concept, finding out the requirements and key characteristics of this topic.

The concept of CBDM was first introduces by Wu, Thames, Rosen & Schaefer (2012) who explored the potentials of utilizing cloud computing for some selected aspects like collaborative design, distributed manufacturing, data mining, collective innovation, semantic web technology and virtualization and proposed to expand the paradigm of cloud computing in the area of computer aided design and manufacturing. In their study they also proposed a comprehensive definition of CBDM and discussed its key characteristics. By relating current research in design and manufacture to CBDM, identification of key research issues and future trends has also been highlighted in the study.

Another study by Wu, Rosen & Schaefer (2013), aimed to address the challenge of information sharing and technical communication during the CBDM product development process by modeling a CBDM system as a socio-technical network. In this paper Social Network Analysis (SNA) was done for visualizing collaborative relationship patterns of the actors in CBDM and the results indicated that SNA allows for visualizing collaborative relationship patterns among actors as well as detecting the community structure of CBDM systems.

Again Wu Rosen & Schaefer (2014) in one of their studies have proposed a new paradigm for product design and manufacturing, referred to as cloud-based design and manufacturing, where a definition and vision for CBDM has been introduced. The study articulates the differences and similarities between CBDM and traditional paradigms such as web- and agent-based technologies, highlighting the fundamentals of CBDM. They have also presented a prototype CBDM system called design and manufacturing cloud or DM Cloud which was developed at Georgia Tech. The objective of developing the DM Cloud was to help students learn the use CAD and engineering analysis and to practice product design and manufacturing in a distributed, networked and collaborative setting.

Wu (2014) have proposed another definition by identifying the key characteristics of CBDM. In this study he had also developed a hypothetical application scenario as an example of the CBDM process which is a manufacturing model of a delivery drone. The study was divided in to two parts of cloud based design and cloud based manufacturing. For the cloud based design part a social network analysis also known as SNA-based approach was proposed to model and analyze information flow and in the manufacturing part stochastic petrinetor SPN-based approach was proposed to model and analyze material flow in the manufacturing of the mini drone. This study has also provided a requirements checklist which was developed to determine the functional needs to meet for a future CBDM system.

To analyze the business side of CBDM, important insights into the economics of CBDM has been provided by Wu, Terpenny & Gentzsch (2015). In their study they identified the key cost factors and potential pricing models that can help decision making on whether migrating to the cloud is economically justifiable. Specifically, the cost breakdown of adopting CBDM is presented. The paper also demonstrates the key benefits using real case study. In addition, a hypothetical application example of manufacturing a delivery drone is presented to compare costs in CBDM with that of traditional in-house design and manufacturing.

Ishengoma and M taho (2014) provides an overview of 3D printing in the developing countries. This paper has explored the state of 3DP in developing countries, and analyzed its opportunities and challenges. Moreover, the study has provided the future insights of 3DP application in developing countries and also presented existing case studies from different developing countries such as: India, South Sudan, Colombia, Uganda, South Africa, Kenya, Trinidad and Tobago and Haiti.

Nayak et al. (2014) shows the integration of digital technology with current prosthetic socket fabrication. The fabrication process presented in this study involved 3D scanning and printing. This paper involved extensive literature survey to compare between the traditional manufacturing of socket and 3D printed socket manufacturing and also demonstrates the feasibility of using 3D scanning and 3D printing technology in manufacturing prosthesis socket to ensure maximum comfort to the patient.

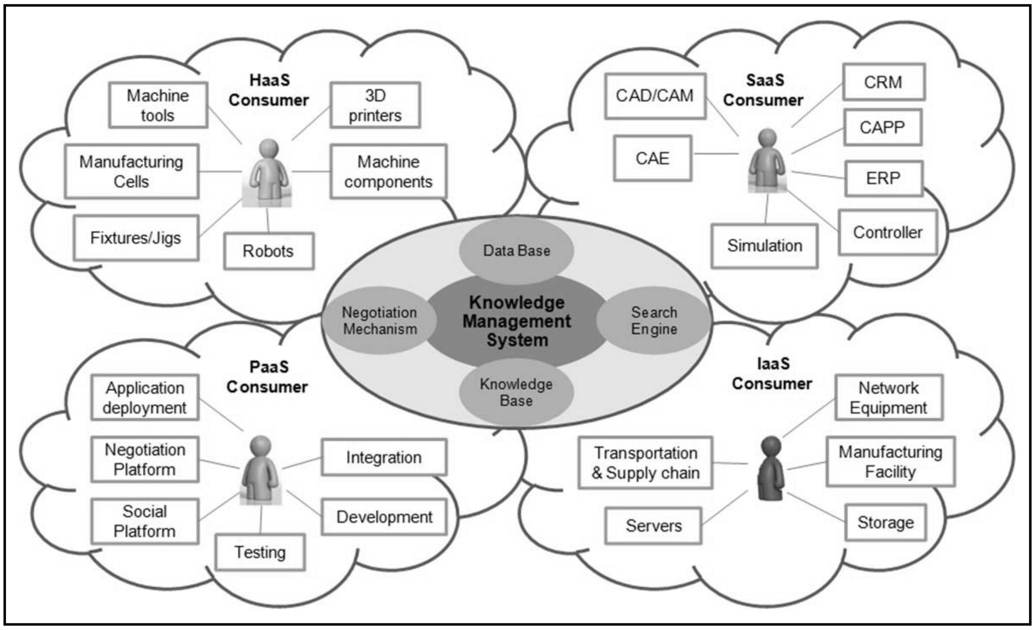
From the literature review it is evident that although CBDM is a newly emerged concept in the field of design and manufacturing, it is already being popular among the designers and manufacturing in the developed countries but yet to be introduced in Bangladesh. CBDM has also attracted the attention many researchers which has led to much development within a very short time. Again the concept of 3D printing has made a revolutionary change in the field of prosthetic production but the study shows that there is still not much improvement seen in the developing countries and there is limited research on the concept of incorporating 3D printing and CBDM. The hypothesis of this study is to test the scope of the concept of 3D printing and CBDM to manufacture transtibial prosthetics in Bangladesh instead of obtaining from abroad.

## 3. Cloud Based Design and Manufacturing (CBDM)

Cloud Based Design and Manufacturing (CBDM) refers to a service-oriented product development model in which service consumers are able to configure products or services as well as reconfigure manufacturing systems through Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), Hardware-as-a-Service (HaaS) and Software-as-a-Service (SaaS) in response to rapidly changing customer needs (Wu 2014). CBDM is characterized by on-demand self-service, rapid scalability, ubiquitous access to networked data, resource pooling, and virtualization. A holistic view of CBDM is presented in the Figure 1.

The definition of CBDM involves various techniques and key terminologies. In order to fully grasp the breadth and depth of CBDM, the definition of CBDM is further divided into two sub-definitions: cloud-based design (CBD) and cloud-based manufacturing (CBM). Cloud-Based Design (CBD) refers to a networked design model that leverages cloud computing, service-oriented architecture (SOA), Web 2.0 (e.g. social network sites), and semantic web technologies to support cloud-based engineering design services in distributed and collaborative environments (Wu, Schaefer & Rosen 2013). One of the examples of CBD services in industry is Autodesk Fusion 360, a platform developed by Autodesk, allowing users to convert photos of objects into 3D models, create or edit 3D models and make prototypes on a 3D printer through the Internet. It helps the design team to collaborate real time based on social network platform and manage the design project all over the Fusion 360 platform with the available state of the art resources to design and analyze industrial and mechanical projects.

**Figure 1: A Holistic View of CBDM (Wu 2014)**




Cloud-Based Manufacturing(CBM) refers to a networked manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, reduce product life cycle costs, and allow for optimal resource loading in response to variable-demand customer generated tasking (Wu et al. 2012).3D Hubs is an excellent example of CBM (Wu, Schaefer & Rosen 2013); it is the largest 3D printing service provider in world. 3D Hubs links 3D printing service providers in a local community with designers who need additive manufacturing services for testing, tooling, and manufacturing. 3D Hubs has been launched worldwide using a community-based 3D printing service model, where digital models can be printed only a few miles away from a customer. According to 3D Hubs, they are developing more function modules such as design for manufacturability and real time quoting.

Wu (2014) also presented requirements of a CBDM networks. In order to formulate any CBDM model the following requirements are to be met. They are Requirement 1: Should provide social media to support communication, information and knowledge sharing in the networked design and manufacturing environment, Requirement 2: Should provide cloud-based distributed file systems that allow users to have ubiquitous access to design- and manufacturing related data, Requirement 3: Should have an open-source programming framework that can process and analyze big data stored in the cloud, Requirement 4: Should provide a multi-tenancy environment where a single software instance can serve multiple tenants, Requirement 5:Should be able to collect real-time data from manufacturing resources (e.g., machines, robots, and assembly lines), store these data in the cloud, remotely monitor and control these manufacturing resources Requirement 6: Should provide IaaS, PaaS, HaaS, and SaaS applications to users. Requirement 7: Should support a search engine to users to answer queries. Requirement 8: Should provide a quoting engine to generate instant quotes based on design and manufacturing specification.

## 4. A Case Study in Perspective of Bangladesh

Bangladesh, being an overpopulated nation where accidents and diseases are particularly regular, have turned into a noteworthy reason for limb amputation and physical incapacities. Attributable to the large number of people with incapacity in Bangladesh there is a growing demand for artificial limbs and extraordinarily for transtibial prosthetics. According to the United Nations more than 13 million people in Bangladesh are believed to have disabilities, with more than 22.5 % of these reported to be individuals affected by physical disabilities (Cochrane *et. al*. 2015). According to the little available data, about 70% of the disabled population has special needs for medical rehabilitation and social integration (Japan International Cooperation Agency 2002) among which a large number of people needs prosthetic assistance. According to the Annual report of CRP (2014-2015), they have provided 103 Lower limbs, 35 Upper limbs and 33 prosthetic hands in the reporting year which shows a huge demand for transtibial prosthetics.

One of the real issues of prosthetic production in Bangladesh is the lack of trained personnel as there is no government training center for orthopedic and prosthetic limb makers. Again being a country of lower-middle income, cost of prosthetic is another unavoidable problem and the traditional process of making prosthetic contribute to a higher cost and production time and lower comfort for the patients as the traditional process of casting is not always a proper fit. Also the process takes up to 7 to 10 days to produce a single piece of below the knee leg. A study of Country profile for Bangladesh done by Japan International Cooperation Agency (2002) shows there are approximately 6 times more people with disabilities in rural areas than urban. But most of the medical and rehabilitation facilities are concentrated in urban areas which makes it difficult to access and these rural people with disabilities have no other alternative than to turn to traditional, often inappropriate or inadequate treatment.

Fortunately, collaboration of 3D printing and CBDM in prosthetic production may contribute in solving these problems by providing cost efficiency, service scalability and business dimensions such as growth, agility, adaptability. It can also be used in order to develop and implement enterprise resource planning systems, enhance the level of accuracy, eliminate multiple visits, enhance the limited design freedom and so on.

But to introduce anything new is a challenge itself and in this case cloud based design and manufacturing is a fairly new making it more challenging to implement in Bangladesh. As of today CBDM concept has never been implemented in any manufacturing industry in Bangladesh and the initial steps are always more critical and risky. To use this concept in the production of prosthetic leg is very challenging and as a highly customized product it can bring unforeseen problems to the manufacturing process. Though the cloud based design process can be helpful for the patients in the rural areas as the design of the socket can be done using 3D scanners in a mobile process, lack of access to the internet may cause problems in cloud service availability. Again in this process 3D printers have a major role to play and Bangladesh is yet to be more enriched in 3D printing industry. Another big challenge in introducing CBDM in Bangladesh is the organizational structure as the cloud framework will change organizational structure. Poor standards in cloud infrastructures and services can also impose a risk of inconsistent service which is provided by different providers. Though Bangladesh is capable of providing these services but there is still a long way to go.

## 5. Formulation of Models

In order to improve the current manufacturing of transtibial prosthetics and incorporating CBDM in it, in this study three manufacturing systems are initially molded. In these three models the implementation of CBDM is done on different levels. The models are described briefly.

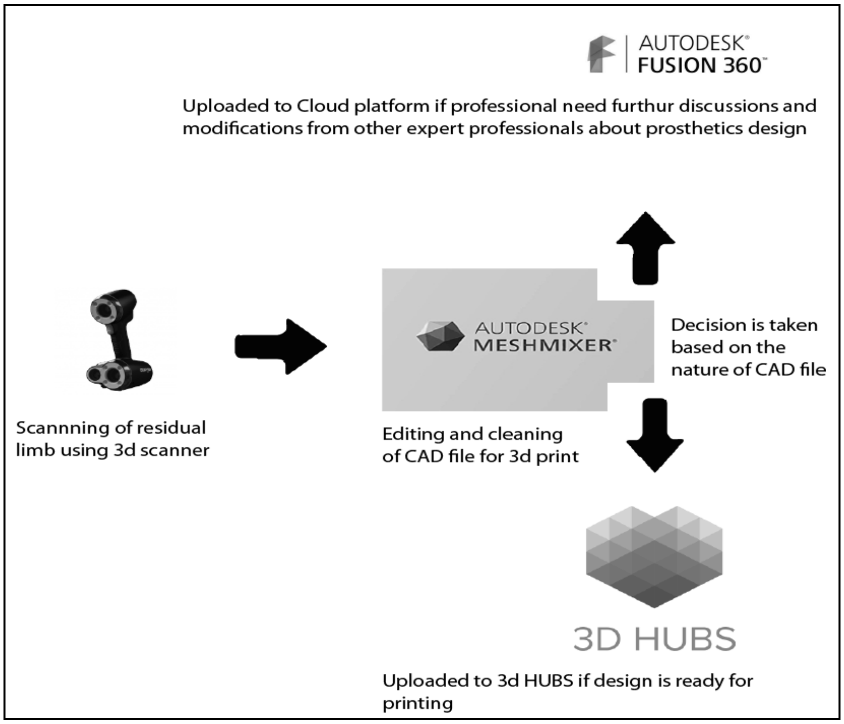
### 5.1 Traditional Method

In this method the traditional manufacturing of transtibial prosthetics are followed without incorporating CBDM. In traditional method of prosthetic production first the measurement of the stump is made. Measurement of the body is performed to determine and calculate the size required for the artificial limb. A silicon liner is fitted. Then a model of the liner is worn over the stump of the patient. A thermoplastic sheet around the model is wrapped later a permanent socket is formed. The plastic parts of the artificial limb are prepared. Die casting is used to create the metal parts of the prosthetics. Finally assembly of entire limb is performed.

### 5.2 Combined Method

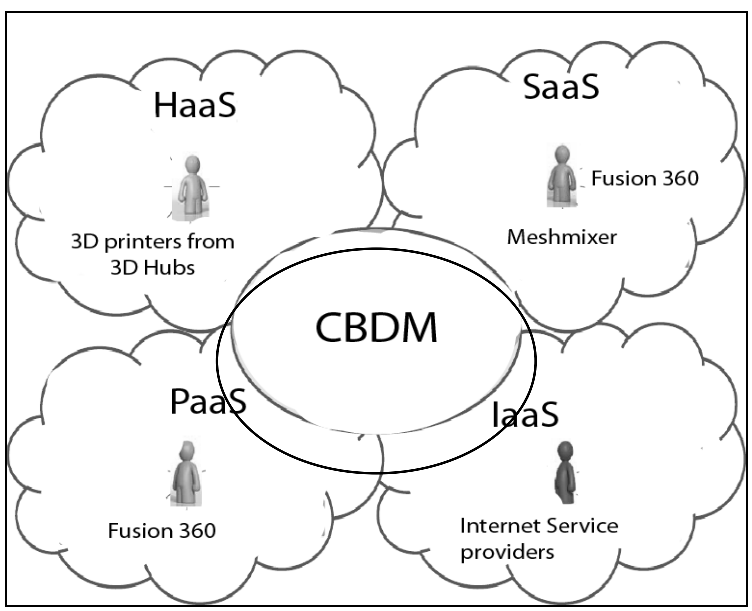
In this method it has been proposed to incorporate the concept of CBDM for socket production only. The stump is scanned using a 3D scanner and using Autodesk Meshmixer and Fusion 360 the design team can collaborate. Using 3D Hubs multiple socket of the patient with better design of socket can be prepared. The other parts are setup with the socket once they have arrived in the traditional method and delivered to the patients. The design process using CBDM concept and 3D scanner is presented in the Figure 2.

**Figure 2: Design Process using CBDM Concept and 3D Scanner**




**CBDM Method:** In order to analyze and understand the usability and feasibility of CBDM in perspective of Bangladesh for transtibial prosthetic production the outer foot along with socket. Similar design and manufacturing process using a 3D scanner and 3D Hubs for 3D printing service providers are utilized. Figure 3 shows the example services used in our CBDM model.

**Figure 3: Example Services used in Proposed CBDM Model**



The researches only explained the comparison between the traditional method and CBDM method but there are no studies or researches that provide the combined method that compare with the traditional method and CBDM method. This study provides such comparison in accordance with three evaluation criteria that are explained below.

## 6. Evaluation of Models based on Criteria

The proposed models are evaluated based on the three criteria. They are

1. Capacity of each manufacturing models for transtibial prosthetic production in a single month.
2. Minimum average time for delivery of prosthetics to the patients using three models.
3. Cost of production of unit prosthetics using these three models.

In order to evaluate the models based on the capacity of models in a single month and the minimum average time for delivery the ARENA simulations software has been used. To calculate the cost of unit prosthetics, product costing method has been applied.

### 6.1 Simulation of the Models using ARENA Software

Using ARENA simulation software all three models for manufacturing of transtibial prosthetics are performed. The following considerations has been made in the simulation of the models.

**Considerations**

1. As the historical data of every step performed during the preparation of lower limb prosthetics has not been found, triangular distribution has been used based on information gathered from the professionals during the data collection period of this research and literatures based on the production of prosthetics has been used.

2. During the simulation, it has been assumed that the inventory of pylon and outer foot has not been gone below the safety stock. In order to focus on the capacity determination of the models and time for production of lower limb prosthetics it has been assumed.

Brief description of the simulation of manufacturing models has been given below. All the models were simulated with 100 replications and warm-up period of 7 days and ran for 30 days with 8 hours per day. The data for simulation has been collected form professionals, literatures on prosthetic manufacturing and 3D Hubs quotations.

**Traditional Model**

The CREATE module in ARENA has been used with the Poisson distribution of 0.7414 per day to initiate the entity that represents the order of prosthetics in the model. PROCESS module of ARENA with a triangular distribution of value 3 days, maximum 3.5 days, min 2 days to represent the casting process of socket. The attachment of outer foot and pylon attachment is also simulated using PROCESS module with triangular distribution of 1 with maximum value of 1 and minimum value of 0.5 day. Assembly of all parts are represented using PROCESS module of triangular distribution of 1 with maximum value of 1.5 and minimum value of 0.5 day.

**Combined Model**

Similar to the traditional method the CREATE module in ARENA has been used with the Poisson distribution of 0.7414 per day to initiate the entity that represents the order of prosthetics in the model. Scanning of the residual parts represents PROCESS module with a triangular distribution of 1 hours with maximum of 1.5 hours and minimum of 1 hour is used. This separation of order is made using a SEPARATE module in ARENA for simulation. As per the huge availability of 3D printing services available in 3d Hubs we have considered there remain at least 10 3D printing service provider available every time a search is made. Basing of the lowest delivery time the order for different sockets are placed. As per the data that we have gathered from 3D Hubs after they have analyzed our drawing we have used triangular distribution of 2.5 days with maximum of 3 and minimum of 2 days. The outer foot and pylon attachment is simulated using PROCESS module with triangular distribution of 1 with maximum value of 1 and minimum value of 0.5 day. Finally MATCH and BATCH modules and PROCESS modules with triangular distribution of 1 with maximum value of 1.5 and minimum value 1 is used to represent assembly works.

**CBDM Model**

Similar to the combined method, the models for the CBDM method has been formed. Except for outer foot production, a PROCESS modules with a set of 10 resources representing 3D service providers with triangular distribution of 3.5 days with maximum of 4 and minimum of 3 days is used. Figure 4, 5 and 6 presents the simulation models of the above mentioned methods.

**Figure 4: ARENA Simulation Model for Traditional Method**

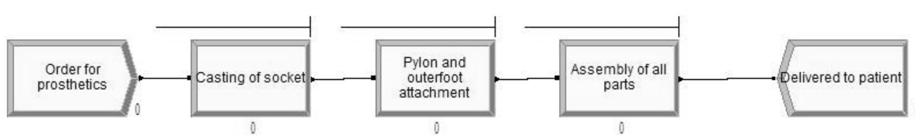


**Figure 5: ARENA Simulation Model for Combined Method**

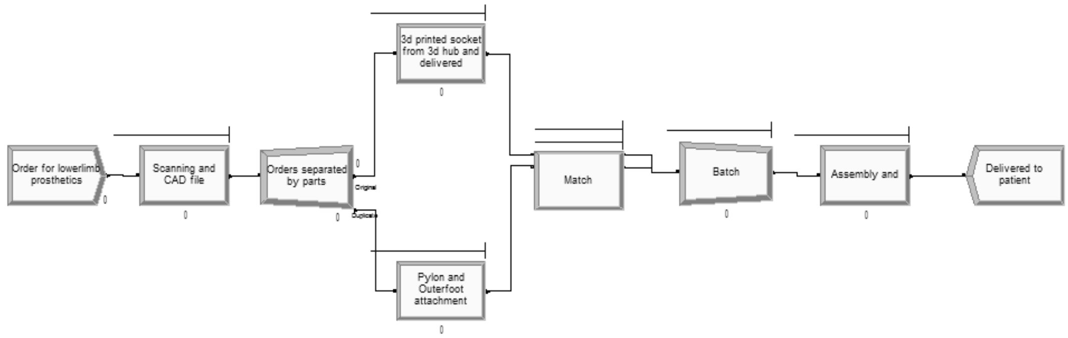
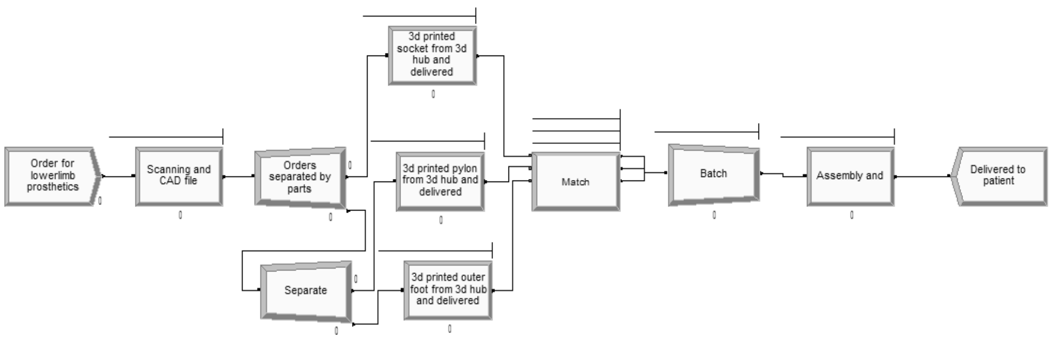



**Figure 6: ARENA Simulation Model for CBDM Method**




## 6.2 Evaluation of Models Based on Product Costing Method

A traditional cost analysis also known as the conventional method of cost calculation is used to estimate the cost associated with the design, manufacturing and assembly of parts. The traditional method of cost accounting refers to the allocation of manufacturing overhead costs to the products manufactured. Traditional costing assigns or allocates the factory's manufacturing overhead or the indirect costs to the items manufactured on the basis of the volume of a cost driver such as the number of units produced, the direct labor hours or the production machine hours. A cost driver is a factor that causes cost to incur, such as the amount of direct labor hours needed to produce an item. This costing system traces resources to cost objects for the cost distribution. A cost object refers to a product or process to which costs are assigned. An activity refers to an action or event in which the cost objects are created.

In conventional costing system the total cost of product includes all costs involved in acquiring or making a product. In this case two main parts of costing are the manufacturing costs including direct material costs and the direct labor costs and the second part is manufacturing overhead which includes indirect material costs, indirect labor costs, transportation etc.

To calculate the total cost first we have listed the cost objects and divided them into manufacturing cost including direct material and direct labor cost and manufacturing overhead cost including indirect material, indirect labor, Transportation cost and electricity bill. In the next step we have determined the cost drivers and calculated how much the cost drivers are consumed. Cost assigned to individual materials and labor is calculated by multiplying the cost driver rate with the amount of cost driver consumed. Finally the total cost is calculated by summing all the individual costs associated with the production. In the cost calculation we have considered 8 working hours per day and 292 working days per year.

In traditional method, depending on the cost driver consumption and the cost driver rates, the materials and labor costs are determined which has given us the manufacturing cost which includes total direct material cost of 5401.02 BDT and total direct labor cost of 12040 BDT. Again we determined the manufacturing overheads including total indirect material cost of 654.5 BDT, total indirect labor cost of 4200BDT, transportation cost of 1500 and electricity bill of 1400 BDT. Finally the summation of all these costs have given us the total cost of producing a single transtibial prosthetic by the traditional method which is 25195.52 BDT. Table 6.1shows the total calculation. In this method, the manufacturing cost is the highest as this traditional process of prosthetic production includes a huge variety of materials, time and labor.

Similarly in the combined method, the manufacturing cost includes total direct material cost of 7099.21 BDT and total direct labor cost of 2400 BDT. Again we determined the manufacturing overheads including total indirect material cost of 4 BDT, total indirect labor cost of 1200 BDT, transportation cost of 2000 and electricity bill of 320 BDT. Which has given us the total cost of producing a single transtibial prosthetic by the combined method of 13023.21 BDT. In this method both direct labor cost and manufacturing overhead cost has been reduced to a large extent because unlike the traditional method the mixed process requires less labor consumption and the only indirect material is consumption of internet service.

Again manufacturing cost in CBDM method includes total direct material cost of 8668.08 BDT and total direct labor cost of 2400 BDT. The manufacturing overheads includes total indirect material cost of 8 BDT, total indirect labor cost of 1200 BDT, transportation cost of 4000 and electricity bill of 320 BDT. Finally the total cost of producing a single transtibial prosthetic using the CBDM method has been calculated to be 16596.08 BDT. In the CBDM method both manufacturing cost and manufacturing overhead cost is increased in comparison to the combined method but it still remain much lower than the traditional method.

**Table 1: Total Product Cost for Traditional Method**

| Manufacturing cost | | | | | | |
|---|---|---|---|---|---|---|
| | **Cost object** | **Activity** | **Cost driver** | **Cost driver consumed** | **Cost driver rate (BDT)** | **Cost assigned (BDT)** |
| Direct materials: | | | | | | |
| | Convection oven | Heating socket | Number of m/c hours | 16 hrs. | 3.42/hr. | 54.79 |
| | Outer foot | Part of prosthetic | Number of item | 1 piece | 2227/item | 2227 |
| | Alignment module | Alignment | Number of item | 1 unit | 1767/item | 1767 |
| | P. O. P. bandages | Cast taking | Length | 2 m | 199.87/meter | 399.74 |
| | P. O. P. powder | Positive mold | Material volume | 4kg | 153.39/kg | 613.56 |
| | Cotton/ nylon stockinet | Cast taking, soft socket, stump sock | Length | 1.5 m | 114.58/m | 171.87 |
| | polypropylene,4mm | Hard socket | Material area | 0.22 m2 | 146/m2 | 32.35 |
| | EVA, 3mm | Soft socket | Material area | 0.0 475 m2 | 1300/m2 | 60.23 |
| | EVA, 6mm | Soft socket | Material area | 0.0425 m2 | 1500/m2 | 63.6 |
| | Welding machine | Finishing | Number of m/c hours | 8hrs. | 0.5 / hr. | 4 |
| | Vacuum pump | Socket thermoforming | Number of m/c hours | 8hrs. | 0.86/hr. | 6.88 |
| | | | | | **Total Direct materials cost** | **5401.02** |
| Direct Labor: | | | | | | |
| | Technician | Prosthetic making | Number of labor hours | 112 hrs. | 75/hr. | 5040 |
| | Physician | Checking patient | Number of labor hours | 56 hrs. | 125/hr. | 7000 |
| | | | | | **Total Direct Labor Cost** | **12040** |

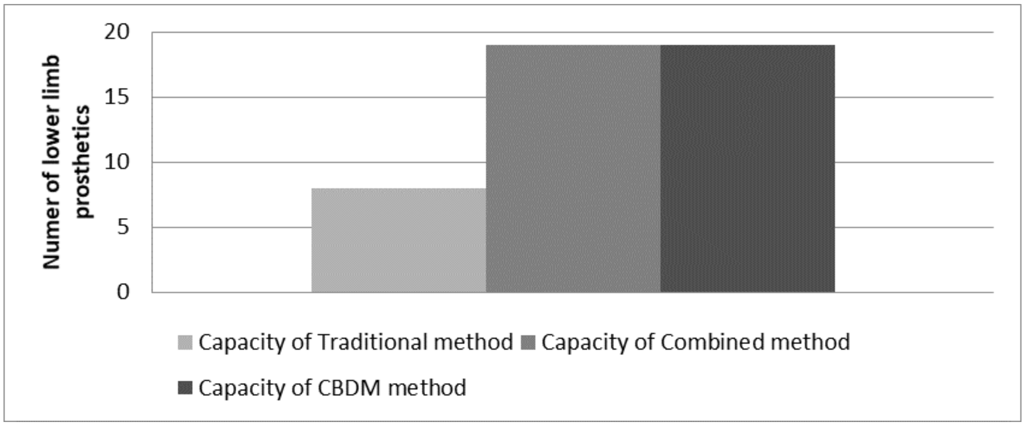
**Table 2: Total Product Cost for Traditional Method (Continued)**

| Manufacturing Overhead | | | | | | |
|---|---|---|---|---|---|---|
| | **Cost object** | **Activity** | **Cost driver** | **Cost driver consumed** | **Cost driver rate (BDT)** | **Cost assigned (BDT)** |
| Indirect materials: | | | | | | |
| | Contact glue | Soft socket | Material volume | 0.5 kg | 380/kg | 190 |
| | Soap | Positive mold | Material volume | 0.5 kg | 250/kg | 12.5 |
| | Talcum powder | Thermoforming | Material volume | 0.25 kg | 800/kg | 200 |
| | Vaseline | Cast taking | Material volume | 0.25 l | 800/liter | 250 |
| | Nails | Positive mold | Number of item | 1 piece | | 0.5 |
| | Welding rod | Welding components | Material volume | 2ft | 0.75/ft. | 1.5 |
| | | | | | **Total Indirect Materials Cost** | **654.5** |
| **Indirect Labor:** | | | | | | |
| | Store officer/material handler | | Number of labor hours | 56 hrs. | 75/hr. | 4200 |
| | | | | | **Total Indirect Labor Cost** | **4200** |
| | Transportation | | Distance | | | 1500 |
| | Electricity | Power | Number of hours | 56 hrs. | 25 / hr. | 1400 |
| | | | | | **Total Product Cost** | **25195.52** |

## 7. Results

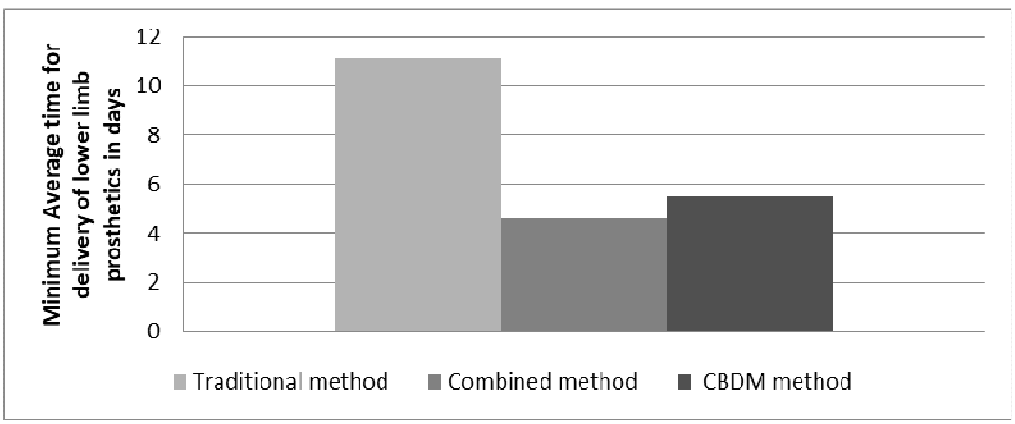
The results from the simulation of the models show the capacity of each models and minimum average time of delivery of prosthetics to the patients. The cost of product manufacturing is obtained from product costing method. From the simulation of the three models for production of prosthetics we have found that incorporating CBDM for transtibial prosthetic production provides more capacity for serving and providing prosthetics to average newly enlisted patient per month. From simulation we have found that in traditional method it is capable of producing 8 prosthetics per month where in the both combined and CBDM method the capacity increases to 19 prosthetics per month. Figure7 presents of capacity of these methods per month.

**Figure 7: Production Capacity of Transtibial Prosthetics by Traditional, Combined and CBDM Method**



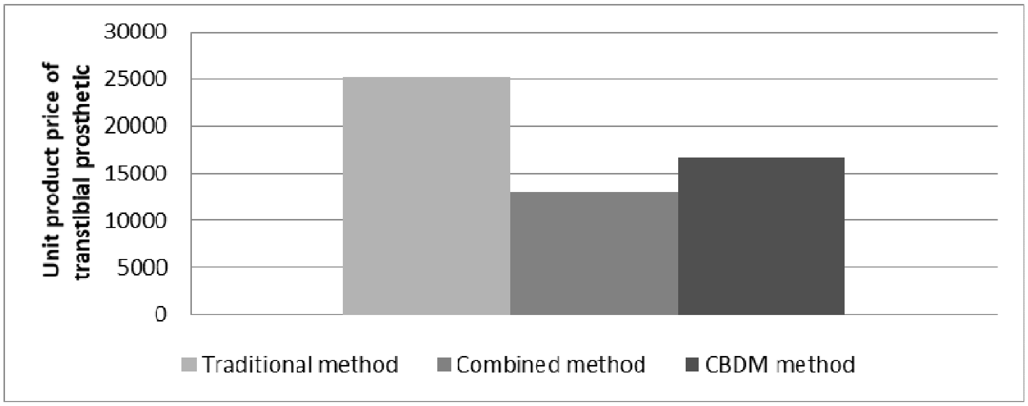

Similarly from the simulation result we have found that time required for prosthetic production in traditional method is 11.1 days, in mixed method where CBDM is implemented only for socket production; the required time is 4.6 days and for CBDM method where both socket and outer foot are produced using 3D printing service provider is 5.5 days. Figure 8 presents of minimum average delivery time of the prosthetics.

**Figure 8: Minimum Average Time of Delivery Of Transtibial Prosthetics by Traditional, Combined and CBDM Method**




To calculate the cost incurred in transtibial prosthetic production in traditional, mixed and the CBDM approach conventional cost calculation method has been used and the results show that the total cost associated with the design and manufacturing of a single unit of Transtibial prosthetic is 25195.52 BDT in the traditional approach, 13023.21 BDT in the mixed approach and 16596.08 BDT in CBDM approach. Unit production cast to produce transtibial prosthetics from each method is presented in figure 9.

**Figure 9: Unit Production Cost of Transtibial Prosthetics by Traditional, Combined and CBDM Method**




In previous researches as mentioned in literature review there is no such comparison within the aforementioned methods in terms production time, capacity and unit product costs as shown in figure 7, figure 8 and figure 9 respectively.

## 8. Conclusions

This research study has discussed about a contextual investigation on the present circumstance of prosthetic production in Bangladesh, examined how CBDM may affect the prosthetic generation industry in context of Bangladesh which is not done in previous researches. To provide a solution of the problems incorporated with the traditional process, this paper presents design and manufacturing models of transtibial prosthetic production in Bangladesh by integrating prosthetic production industry with a vast design and manufacturing cloud. To determine the most scalable, time and cost effective manufacturing system three different design and manufacturing models are primarily proposed which integrates CBDM and 3D printing of parts at different levels of production. These hypothetical models are evaluated using simulation models created in ARENA simulation software and comparing the simulation results of capacity and production time. Again the business side of these models are compared by calculating unit product cost incurred in each individual methods of production. And finally after evaluation of the criteria the results indicate that, among these three models, the combined model utilizing both conventional and CBDM system where the socket production will follow cloud based design and manufacturing system while the outer foot is produced traditionally has been proven to be the best alternative. The proposed model of cloud based transtibial prosthetic production not just presents another plan of action for prosthetic production, additionally gives a promising approach to deal with actualize CBDM in Bangladesh and accumulating SMEs into a cyber - physical virtual manufacturing society in the near future. This work along with other researches reinforces the implementation of CBDM to get significant benefits over the traditional system. The limitations as well as the future recommendations of this work include practical implementation of the proposed model of transtibial prosthetic production which will give precise data on how it may influence the prosthetic assembling industry in Bangladesh. Also the suitable material selection for 3D printed prosthetics and implementation of CBDM in the rapidly developing SME scenario are the future scope of this study.

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