INTEGRATION BETWEEN ADDITIVE MANUFACTURING AND VALUE CHAIN TECHNIQUES AND ITS ROLE IN REDUCING COSTS

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ABSTRACT

The research aims to clarify the concept of additive manufacturing technology, its importance, advantages, tools and mechanism of work, as well as clarifying the concept of value chain technology and identifying its most important pillars, and then knowing the integration between the additive manufacturing technologies and the value chain through three stages (pre-production stage - production stage - post stage Production) and the extent of its impact on the cost, whether negatively or positively. The manufacture of prostheses in recent years is considered one of the important industries in Iraq, especially with the continued ignition of hotspots of armed conflicts and the occurrence of terrorist bombings, but it suffers from a large increase in costs.

The authors reached a set of conclusions, the most important of which are: The application of additive manufacturing technology in integration with the value chain technology leads to the reduction of the value chain links through digital intervention (computer-aided design CAD and computer-assisted manufacturing CAM), which gave the production line many advantages, this interaction leads to granting the ability to produce Products with difficult engineering designs with less resources and time, which facilitates this in obtaining products with an appropriate price and quality.

Keywords: Additive Manufacturing, Value Chain, Cost Reduction.

INTRODUCTION

Creative minds all over the world have the ability to imagine things that would revolutionize any industry, as a result of the continuous and rapid changes in the contemporary manufacturing environment, and from this standpoint came thinking about the need to manage costs through the use of contemporary technologies that reduce costs without compromising quality. The product or service provided, including additive manufacturing and value chain technologies, whose use has increased dramatically in recent years. As the additive manufacturing technology recycles the raw materials and manufactures and assembles the product on its own, which leads to the rapid crossing of the product from the design stage to the full production stage directly, and the value chain technology focuses on analyzing the basic functions of activities starting from research and development through production, marketing, distribution and customer service to determine the contribution Each partial process within each job in terms of the value it adds to the customer. The study will provide a brief overview of Additive manufacturing technologies and the value chain and integration between them through three stages (pre-production stage - production stage - post-production stage), and Calculating additional manufacturing costs during the three chain stages and comparing them with traditional manufacturing costs.

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LITERATURE REVIEW AND PREVIOUS STUDIES

The study altayar focused on Benefiting from the computerized complete digital accounting and production system for the purpose of making a turning point in the fields of accounting notation, in addition to preparing smart digital real-time reports to make real-time decisions for the purposes of keeping pace with market control and global competition, (Griffin, 2017) determined Sensitivity analysis can be performed, providing a more realistic prediction of investment results. This procedure is useful as a simple process by which to assess whether production of a particular part should be carried out by additive manufacturing rather than by conventional methods, As for the study (Staffansn & Ragnartz, 2018), The use of additive manufacturing in product development has been shown to have huge potential to be extremely time-efficient and economically profitable.

The theoretical framework was built to study the complementary relationship between the two technologies of Additive Manufacturing and the value chain, and the extent of its impact on costs, whether positive or negative, By defining the research problem, which is the dependence of economic units on traditional production methods, which in turn leads to a set of problems, including the presence of types of waste that accompanies the production process, the emergence of defective production, as well as the high costs of materials, which represent a large proportion of the total costs, Based on the above, the problem can be formulated through the following two questions:

1. Does the use of integration between additive manufacturing techniques and the value chain help to reduce costs in the research sample?
2. Does the integration between the techniques of additional manufacturing and the value chain contribute to overcoming the problems that the traditional systems of cost and management accounting suffer from?

Research Aims

The research seeks to achieve the following goals:

1. Clarifying the knowledge foundations of additive manufacturing technology.
2. Clarify the knowledge foundations of value chain technology.
3. Clarifying the knowledge bases for cost reduction and how to achieve it based on the integration between additive manufacturing techniques and the value chain.
4. Clarify the complementarity between them in the center, the research sample, and indicate how to reduce the costs of products.

Research Hypothesis

Depending on the presentation of the research problem and to achieve its objectives, the following main hypothesis was formulated:

"*Integration between additive manufacturing technologies and the value chain contributes to cost reduction*"**.**

The following two sub-hypotheses are derived from it:

1. Additive manufacturing technology contributes to cost reduction.
2. The value chain technology contributes to reducing costs.

Research Methodology

This research is based on two approaches:

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1. The deductive approach: represented by relying on Arabic and foreign references, sources, periodicals, and research, as well as relying on the Internet.
2. The inductive approach: represented by several means to obtain the necessary data and information from the Chest Canal Center for Prostheses and Medical Supports to complete this research and test its hypotheses.

A Default form for Search Variables

The Figure 1 below shows the research model through which the research hypothesis is tested:

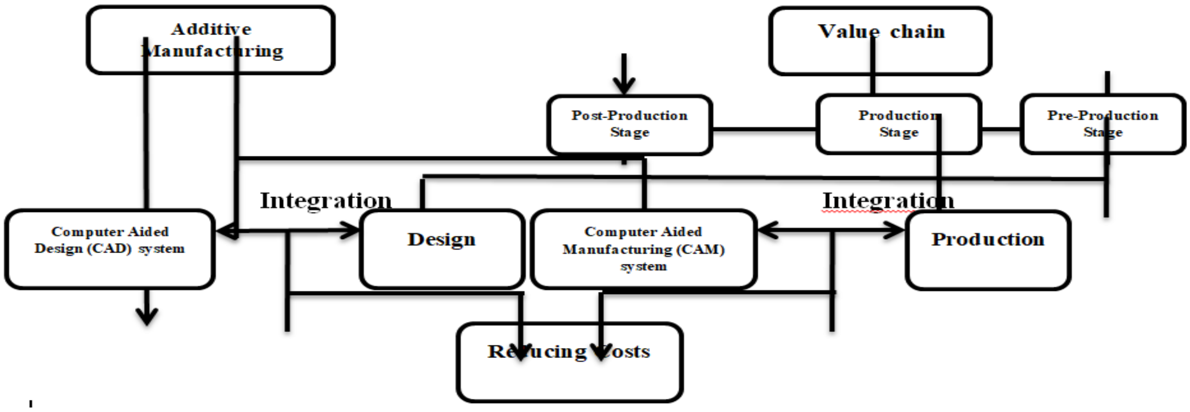

Figure 1
RESEARCH HYPOTHESIS

Additive Manufacturing Technology

Additive manufacturing technology is one of the modern technologies at the present time, as it seeks to achieve many advantages and benefits when applied in economic units, as it provides the easiest methods and programs to design products with more accuracy and ease, as well as shortening the waste of time and costs.

The concept of Additive Manufacturing Technology

Final design has always been constrained by the limitations of manufacturing technology, product designers and design engineers need to strike a balance between product functionality and quality, while also reducing cost. This has traditionally been done by following a guideline called design for manufacture and assembly, which focuses on reducing product complexity to reduce manufacturing costs. However, with additive manufacturing technology, product complexity is no longer tied to manufacturing costs, which liberated designers, allowing designer intent to be realized at low cost (Hinchy, 2019:3). Points of view differed on finding a comprehensive definition that explains additive manufacturing over the years, and a number of researchers have tried to define it.

It is defined as "*a technology in which physical parts are manufactured using computer-aided design and objects are created on a layer-by-layer basis. Usually, these procedures are called toolless processes*." (Haleem & Javaid, 2021:412).

It is also defined as usually referring to "*a computer-aided design (CAD) process for creating three-dimensional objects by layering materials such as plastics, composites, or biomaterials to create objects that range in shape, size, hardness, and color*." (Ntakana, 2021:11).

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From the above, it can be said that additive manufacturing is a production system that operates on the method of accumulating raw materials without wasting it in a short time and at a lower material cost, through which the materials are collected layer by layer through the manufacture of a three-dimensional model (3D) with the help of a computer (CAM), and without The need for manual work, which improves the productive process and reduces engineering restrictions through computer-aided design (CAD).

Advantages of Additive Manufacturing Technology

There are a number of advantages that additive manufacturing technology enjoys, which makes it an important source. Its advantages are summarized as follows:

1. Flexibility: Additive manufacturing technology operates according to a policy characterized by a great deal of flexibility in manufacturing. It is possible to manufacture almost any shape. (Alogla et al., 2021:3)
2. Low costs: Organizations adopt additive manufacturing technology in order to save a lot of costs that may be wasted due to exorbitant costs when compared to parts that are manufactured according to the traditional method. (Bauer & Malone, 2015: 3)
3. High quality: Additive manufacturing technology is distinguished by following all the steps and standards of high quality compared to other types of manufacturing. (Wozniak et al., 2022:834)
4. Low inventory: Economic units that adopt additive manufacturing technology do not suffer from the problem of filling warehouses with goods, commodities, and raw materials. (Durach et al., 2017:961)
5. Reducing waiting time: Relying on additive manufacturing technology operations, economic units no longer need to put waiting lists for customers, as waiting times will be reduced and thus additive manufacturing technology will improve the sales process and the commercial and economic boom of the economic unit (Durach et al., 2017: 963).

Additive Manufacturing Technology Processes

The concept of additive manufacturing includes a group of different tools divided according to the ASTM F2792 standard, all of which share the concept of "*layer by layer*" manufacturing, but each has different characteristics in terms of materials, technical capabilities, limitations, etc., the most frequently used tools will be addressed, AM operations are classified. Table 1 shows the seven categories of the additive manufacturing process, which are as follows:

Table 1
THE SEVEN CATEGORIES OF THE ADDITIVE MANUFACTURING PROCESS

	Operation type	Description	Tool	Materials
1	Powder bed fusion (PBF)	Thermal energy selectively fuses areas of the powder bed	Electron Beam Melting (EBM), Selective Laser Sintering (SLS), Selective Heat Sintering (SHS), Direct Metal Laser Sintering (DMLS)	Metals, Polymers
2	direct energy deposition (DED)	Concentrated thermal energy is used to melt materials by melting while the material is deposited	Laser Metal Deposition (LMD)	Minerals
3	Material Extrusion (ME)	The material is selectively distributed through a nozzle or orifice	Fused Deposition Modeling (FDM)	Polymers

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4	Water pumping photopolymerization (VP)	A liquid photopolymer in a vessel is selectively processed by light-activated polymerization	Stereolithography (SLA), Digital Light Processing (DLP)	Photopolymers
5	Binder Binder (BJ)	The liquid bonding agent is selectively deposited to join powder materials	Powder bed and inkjet head (PBIH), gypsum based 3D printing	Polymers, Sheets and Metals
6	Material jetting (MJ)	Building material droplets are selectively deposited	multi-jet modeling (MJM)	Polymers and Waxes
7	paper lamination (SL)	Sheets of material are joined to form an object	Laminated Body Fabrication, Ultrasonic Uniformity (UC)	Paper and Metal

Source: (Moshiri, 2020; Shahrubudin & Ramlan, 2019)

Value Chain

The value chain is one of the newest and most popular trends of our time, and the concept of value in the value chain is multifaceted and complex. Companies that undertake value chain management practices seriously in their organizations often aim to improve their performance in terms of, for example, higher profits, better market responsiveness, and long-term competitive advantage. There are no specific ways to add value in goods or services, but they have emphasized on Methods that reduce cost and time without compromising the quality of products in efficient and effective ways.

Value Chain Concept

Value is achieving benefit and interest for the beneficiary and the user. Value can be seen as a function of quality, service and cost. The main purpose of value studies is to improve value, which means obtaining higher quality at the lowest possible costs. Some confuse the meaning of value with the meaning of price or cost, and often the value is measured on the basis of cost only, although the high cost does not necessarily mean the high value (Almquist et al., 2016:4).

Points of view differed on finding a comprehensive definition that clarifies the value chain over the years, and a number of researchers have tried to define it.

It was defined as "*a set of activities and services necessary to bring products or services from production to the final market*" (Msolla, 2020:5).

It was also defined as "*a group of sequential activities that aim to increase the customer's perceived value of the products or services of the economic unit to ensure his loyalty to it and to achieve a competitive advantage*" (Saad & Hassan, 299: 2019).

Based on the foregoing, the value chain can be defined as "*one of the management accounting techniques for analyzing and studying an interrelated chain of activities necessary for the production of goods or services to reach the final market, starting from research and development activity, product design activity, operations activity, production, marketing and distribution, all the way to providing services to customers*.", So that these activities interact with each other, which helps to increase the added value of the customer and create greater value for the economic unit, which achieves a competitive advantage for it.

Value Chain Activities

The value chain consists of six main activities, which are as follows: (Horngren, et al., 2012:6).

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1. Research and development: It is represented in generating and experimenting with ideas related to new products, services or processes.
2. Product Design: It relates to the detailed planning and engineering of products, services or processes.
3. Production: This is done by obtaining resources, coordinating and assembling them to produce the product or perform the service.
4. Marketing: It consists of promoting and selling products or services to customers.
5. Distribution: It is the delivery of products or services to customers.
6. Customer Services: It focuses on providing support to customers after the sale process.

Advantages of the Value Chain

Among the most prominent advantages of the value chain are the following: (Sorour, 2018: 10).

1. Improving the cost position of companies, and thus supporting competitiveness in the local and global market.
2. Providing the management with the opportunity to analyze cost complexes and their causes, which enables them to reduce their effects on the company.
3. Determining new groups of cost vectors as a result of the new division of the company's activities, which contributes to the possibility of applying costing technology based on activities.
4. Focusing on reducing costs and finding ways to improve returns from the value chain.
5. It helps to raise performance and identify opportunities that contribute to the development of work.

Reducing Costs based on the Integration of Additive Manufacturing Technologies and the Value Chain

For traditional manufacturing techniques, there is a direct link between component complexity and cost. As component complexity increases, manufacturing cost also increases. This cost increase is mainly due to both tooling costs and extended processing time. As the components become more complex, the tools must become more complex and more assemblies may be required. It is impossible to manufacture some complex geometries using conventional manufacturing, no matter the cost. In addition to these points, more assembly may be required to complete highly complex components, which again increases costs. Additive manufacturing, on the other hand, provides almost complete engineering design freedom, which can be attributed to the layer-by-layer manufacturing process. In addition, the complexity of components is independent of the cost of additive manufacturing. This means that design engineers can produce almost any shape imaginable, without the attendant increase in manufacturing costs that would be incurred using traditional manufacturing techniques. One of the primary areas in which additive manufacturing maintains an average over Traditional manufacturing is lacking in tooling requirements and associated costs. Through this, design engineers can produce nearly any geometric shape from a range of materials, including polymers, metals, and ceramics. This has enabled design engineers to produce complex organic shapes, such as skeletons of bones. Customized human, multi-material components can be designed and manufactured, with built-in functions and in-house features. The ability to quickly prototype these things during development and testing also reduces time to market, as complex tooling doesn't have to be designed or manufactured, it can be done digitally without the need for tooling (Salvador & Garcia, 2019: 9-10).

The value chain requires expanding the scope of focus beyond the borders of the economic unit, that is, understanding the nature of the relationship between the economic unit and customers on the one hand, and the nature of the relationship with suppliers, as understanding the nature of the relationship between the economic unit and customers leads to knowing how much the customer pays in exchange for obtaining the products of the

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economic unit. And to know the total costs incurred by the customer throughout the customer's value chain, and then this determines the opportunities and methods of reducing costs that the economic unit must take, and the focus on reducing costs must also be on the suppliers of raw materials; This is because raw materials constitute a large proportion of the total costs, and therefore the processing of low-quality raw materials will lead to an increase in quality costs in the rest of the value chain activities. If a supplier provides low-quality raw materials, this will cause the economic unit to incur restart costs. Because of the low quality of the product sold as a result of the low quality of the inputs from the raw materials, and therefore the production of a low-quality product will lead to lower sales, lower revenues and profits, lower market share and lose its competitive advantage and strength, the full use of additive manufacturing reduces the unit cost significantly through the use of high-quality materials Good quality In addition, one type of material can be used to produce a specific part, and additive manufacturing affects not only production costs, but also the use of the final product, this technology allows the manufacture of products that may not be possible using traditional methods, these products may have capabilities new, extended shelf life, or reduce the time, labor, or natural resources required to use these products (Patel et al., 2016:890).

Also, there are some basic guidelines that a design engineer must follow to ensure that manufacturing costs are minimized: (Hinchy, 2019:5).

1. Reducing handling time: Parts handling can be thought of as loading a component into the machine or processing a part of it.
2. Ease of insertion: During manufacturing, products can be made faster if the assembly process is simple and straightforward. When designing a collection, it is a good practice to design parts that are easy to assemble.
3. Reducing the number of parts: Reducing the number of parts is an important guiding principle which in turn reduces costs. By consolidating many separate parts into fewer parts, manufacturing and assembly time can be reduced, as well as costs.
4. Modular design and multifunctional parts: By using a modular design, costs can be reduced, and the sub-components used in the assembly are less diverse.
5. Avoid common manufacturing defects: Common manufacturing defects are well understood. For example, for injection molding, if the walls of the mold are too thin, the material may not be completely filled—leading to product failure, similarly, with casting metals.

The most important effects of additive manufacturing are evident on the value chain, as it is the mother system that brings together the rest of the accounting systems, and it serves as a display screen that shows the causes of total product costs for the purpose of rationalizing them as much as possible, given that each activity adds cost and is supposed to add value, and since adding values with a new system without Adding costs is achieved in the additive manufacturing value chain, which clearly shows the following: (Al-Tayyar, 2016: 85)

1. Reducing resources and limiting them to (production elements that will be reduced in the future, which are printing, scanning and software), in contrast to the resources of the traditional chain.
2. Reducing the parties to the chain and limiting them to the customer and the designer, unlike the traditional parties as defined by Al-Ansari (the interaction of several parties, such as the supplier, the organization’s departments, and the distributor, and all these parties add value in several phases to the supply chain operations).
3. Reducing sequential activities to multiple episodes in traditional industries as defined by Porter (as a group of interrelated activities together to create products that work together starting from the use of raw materials until the delivery of the product to the final customer) for the purposes of:

a. Arranging the performance of the economic unit
b. Identify opportunities to develop the organization's business
c. Improving decision-making

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The transformation of manufacturing systems from material removal to addition with a single-stage machine and open source will achieve a significant reduction in costs (current and future). As for the form of chain activities with an activity or two activities that start and end with the customer, and shorten what is between them through the customer's request for a specific design of the product and its manufacture, direct delivery to it, and pruning of the traditional value chain activities by the value chain of additional manufacturing with one printing activity that alone performs the manufacturing, selling, processing and distribution process and achieves integration activities.

An Introductory Summary of the Research Sample

Sader al-qana Center for Prosthetics is a specialized center for the manufacture of prosthetic limbs and medical supports of all kinds, as well as providing physiotherapy services. The level of Iraq, where prostheses of both upper and lower types, in addition to orthotic supports, are manufactured, equipped and provided free of charge to those who deserve it. The center receives auditors from the capital and other governorates, especially those with lost limbs and those affected by several reasons, including terrorism, bombings, diabetes and congenital deformities**.**

Justification for Selecting the Sample

Sader al-qana Center for Prosthetics and Medical Supports was chosen to be the research sample, for the following reasons:

1. The manufacture of prostheses and orthotic or alternative devices has been considered, in recent years, one of the important industries in Iraq, especially with the continued ignition of hotbeds of armed conflicts and the occurrence of terrorist bombings.
2. The high costs of prosthetic limbs, and the most important reasons for their high costs are due to the high cost of purchasing raw materials that go into the manufacture of limbs and the existence of complications in securing them.
3. The manufacture of prosthetic limbs requires a lot of effort and time in order for the product to fit the customer's requirements in terms of measurements and comfort in use. Despite the high costs of the materials used in the manufacture of prosthetic limbs, it may not guarantee the manufacture of high-quality prostheses.

While the lower prosthesis above the knee joint (AK) was chosen, for the following reasons:

1. Loss of the lower extremities is one of the cases most reported in the center and the most popular among patients.
2. The continuation of the production process, starting from the raw materials needed in production until reaching the final product, in addition to the availability of the necessary data.
3. The cost and sales importance of the product compared to the products of other parties.

Above Knee (AK) Prosthesis

Above-the-knee prostheses, as shown in Figure 2, usually consist of four main components, which are as follows:

1. The mold (Socket): It is the most important part of the prosthesis as it determines the degree of success of the prosthesis, as it is the mediator between the patient and the prosthesis, in addition to being the part that is manufactured in the center unlike the rest of the other parts.
2. Prosthetic Knee: The prosthetic knee joint is one of the most important components of the prosthesis for above-the-knee amputees.

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3. Leg (Pylon): The primary purpose of the leg is to transfer vertical loads generated by the weight of the amputee to the foot and to the ground.
4. Prosthetic Foot: It is the lower part of the prosthetic leg. It should ideally mimic the function of the real foot as much as possible by providing a safe platform, dealing with variations in terrain, and allowing the user to walk in a natural and symmetrical manner .

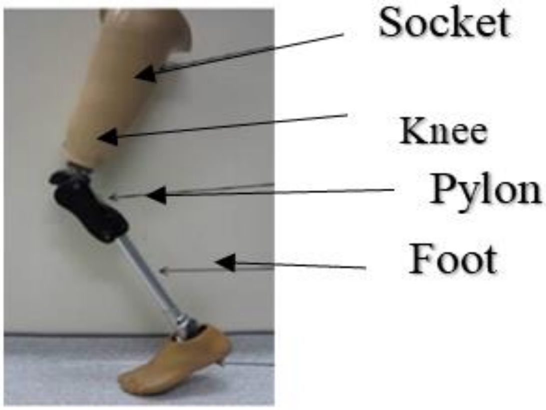

Figure 2
THE MAIN COMPONENTS OF THE PROSTHESIS
Source: "lower-limb prosthesis main components"(Rossi et.al, 2017)

Calculating the Cost of the Artificial limb above the Knee Joint from the Center's records

To achieve the desired goal of the research; Transfemoral (above knee [AK]) costs have been determined as follows:

1. **The cost of materials involved in the production of the prosthetic limb:** According to the technological path of the exchange rates of the materials entering the product for manufacturing a prosthetic limb mold above the knee joint, the total costs of the materials involved in its manufacture are (5,514,741) dinars. of costs; This is because the center was not granted sufficient powers to enter into contracts for the supply of materials and was not granted sufficient powers to disburse the amounts related to materials, and this led to this increase in material costs.
2. **Wage costs:** The costs of wages represent a large percentage of the total component of the cost of the above-knee prosthesis compared to the rest of the elements, and it was the reason for the high cost of the product. The number of employees in the factory reached (36) employees distributed among (5) departments, and the total wages per month amounted to (25,378,922) dinars The researcher adopted the monthly wages due to the presence of a large demand for prostheses above the knee joint, which amounted to (22) requests, and for the month of July, of which only (12) requests were completed, even if the annual wages were adopted, which amounted to (64304,547.0) dinars in calculating the cost of the limb. It would have been very large and led to a distortion of the cost of the party.
3. **Indirect costs:** Indirect costs include (indirect materials, indirect wages, and costs that are spent on the production services departments, that is, the departments that provide services for all products, which belong to more than one product and are difficult to link and allocate directly to one unit), the amount of indirect costs amounting to (10,717,339) dinars, and it is the largest part of the process of manufacturing the limb and the reason is due to the increase in indirect wages, in addition to the presence of many machines used for the manufacturing process.
4. **Administrative costs:** The administrative costs include the wages for administrative positions for the month of July for the year (2021), that the number of administrators is (6) employees, and the total administrative costs for a prosthetic product above the knee joint for the month of July amounted to (6,921,853) dinars, in addition to the absence of marketing costs for the Canal Chest Center.

The cost of one unit of a prosthetic product above the knee joint is calculated based on the previous data and according to the following Table 2:

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Table 2
COSTS FOR THE PROSTHESIS PRODUCT BELOW THE KNEE JOINT FOR THE MONTH OF JULY (2021)

Details	Costs
Direct materials cost	8,27,21,115
Direct wage cost	2,53,78,922
indirect manufacturing costs	1,07,17,339
Administrative costs	69,21,853
cost of spoilage	1,04,02,751
total	13,61,41,980
÷the number of units produced	15
cost per unit	90,76,132

Source: Prepared by the Authors

Depending on the previous data, and in light of the center's information, the cost of the prosthesis above the knee joint was calculated, and it was found that its cost was very high, amounting to (9,076,132) dinars.

Reducing Costs based on the Integration of Additive Manufacturing Techniques and the Value Chain

A comprehensive overview will be given through the cost on the basis of each activity until the end of the post-production stage, through the following main equation:

$$\boldsymbol{Total_{Cost}} = (\boldsymbol{C_{Perp}} + \boldsymbol{C_{Procssing}} + \boldsymbol{C_{Post}}) \ldots\ldots\ldots\ldots\ldots (\mathbf{1})$$

$Total_{Cost}$ = The total cost of the activities
C_{Perp} = The cost of pre-production activities
$C_{Procssing}$ = cost of processing activities
C_{POST} = Cost of post-processing activities

Cost of Post-Processing Activities

This stage includes the cost of the R&D and design activities as well as the costs of the machine preparation activity. The cost of wages and pre-production indirect costs for the AK party include the design wages, which include the cost of converting the CAD file into an STL file, choosing the part orientation, creating support structures, and transporting STL file to the AM system, the machine preparation costs will calculate both the wages and the machine time required to add materials and heat the machine, as well as the indirect industrial costs of the design and machine preparation activities.

Research and Development

For the purpose of application, it is necessary to replace the current production machines with 3D digitization techniques and additive manufacturing techniques. The center can view them through the printer manufacturers' websites on the Internet, correspond with them, and purchase them.

Design

Since a large part of this project is implemented in a computer-based environment, especially the design activity, it is necessary to use computer-based design and engineering programs, with regard to these programs**:**

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1. The Meshmixer program can be obtained directly from the Internet. It is considered one of the best and most widely used programs for modeling 3D designs and it is free. It can edit 3D scans directly without any file conversion between steps.
2. Solid works (SW) program is the main program for computer-aided design (CAD) which is an industry leader, and for computer-aided engineering (CAE), it is used to design solid models, and the design process often begins with making a two-dimensional drawing that gives a three-dimensional shape through Extruding the drawn design, (11,167,460) Iraqi dinars, annual subscription with licensing fees for a period of (10) years, ie: equivalent to (93,002) dinars per month.
3. ABAQUS/CAE software is a software application used for modeling and analyzing mechanical components and assemblies (pretreatment) and visualizing the result of finite element analysis ABAQUS education version is available for free.

The center can exploit the additional manufacturing machine for a number of years, as it is the first in the Iraqi labor market and there is no competitor to it despite the issuance of new generations in the global market. The useful life of the printer is 10 years so that competitors in the private sector will be alerted and introduced. To the Iraqi market, because industrial printers are in a stage of development and rapidly spreading all over the world. The following Table 3 shows the data required to calculate activity costs, which have been clarified from the aforementioned data.

Table 3
DATA REQUIRED TO CALCULATE STAGE COSTS

Pre-production costs		
Abbreviation	Element	Details
N	number of parts	4 units
O_1	Scanning fee rate	14,547 dinars/hour
O_2	Design wage cost rate	138,106 dinars / hour
O_3	Machine setup cost rate	34,064 dinars/hour
T_{Prp}	Pre-production time	2.30 hours
H_1	Indirect cost rate	20,439.3 dinars/hour

Source: Prepared by the Authors

After calculating the costs of the two activities, wage costs amounted to (429,449.3) dinars, and indirect costs amounted to (47,010) dinars. The costs of this stage are calculated through the following equation:

$$\boldsymbol{C_{Perp} = C_{L1} + C_{OH1} \dots\dots\dots\dots\dots\dots\dots (2)}$$

C_{Perp} = Pre-production activity costs
C_{L1}= cost of wages
C_{OH1} = Industrial indirect cost

Therefore, the costs of the pre-production stage can be calculated with its three activities, as follows:

$$C_{Perp} = 429{,}449.3 + 47{,}010$$
$$= 476{,}459.3$$

Production Stage

To calculate the cost of the elements of the production stage, the parameters of the four parts must be determined and the time and quantity of materials required for their completion must be determined, knowing that the construction rate is (8.4) cm3 / hour and the thickness of one layer is 0.3 cm3. At the beginning, the mold is manufactured, whose

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parameters can be determined relatively based on the weight. Previously selected patients (70-90) kg, table (16) shows the parameters of each part separately that will be printed.

Socket Manufacturing

The mold needs (2.3) hours to be printed, and the amount of titanium materials that need to be used for construction is (0.543) grams, and the supporting structure needs (0.498) grams, since the building material and the support material for the building structure is the same material, which is titanium. Therefore, the costs of the materials used to produce the mold are calculated as follows:

$$98{,}501\times(0.498+0.543)$$
$$98{,}501*(1.041)$$
$$= 102{,}540 \text{ dinars}$$

Leg Manufacture

The manufacture of the leg requires (0.36) minutes to be fully printed, and the amount of materials needed for construction is (0.335) grams, and the supporting structure needs about (0.272) grams, so the costs of the materials used to produce the leg are calculated as follows:

$$98{,}501\times(0.272+0.335)$$
$$98{,}501*(0.607)$$
$$= 59{,}790\text{dinars}$$

Manufacturing the Knee and Foot

To print the foot and the knee, it takes (1.2) hours, while the amount of materials needed for the construction of the two parts is (0.545) grams and the supporting structure for the two parts needs (0.439) grams. The costs of the materials used to produce the knee and the foot can be calculated as follows:

$$98{,}501\times(0.439+0.545)$$
$$98{,}501*(0.984)$$
$$=96{,}925 \text{ dinars}$$

The cost of materials for the production stage can be calculated by adding the costs of materials for the three manufacturing processes, as follows:

$$96{,}925 + 59{,}790 + 102{,}540$$
$$= 259{,}255$$

From the foregoing, it is clear that the costs of direct materials for the four parts amounted to (259,255) dinars, and the cost of materials through the use of additive manufacturing is significantly lower compared to the costs of traditional manufacturing, as many materials are involved in the manufacturing process, in addition to the fact that these materials are expensive.

All that the technician will do during the printing of the four parts is to monitor the manufacturing process only, as his wages depend on the hours of monitoring the printing process during this stage, unlike the traditional manufacturing process in which many jobs are done, so the process needs more than one worker, which increases the costs of direct wages for the party, The technician's hourly wages are (34,064) dinars.

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The following Table 4 shows the exchange rates, quantities, times and prices required to implement the production stage.

Table 4
EXCHANGE RATES, QUANTITIES, TIMES AND PRICES REQUIRED TO IMPLEMENT THE PRODUCTION STAGE

Production		
abbreviation	Element	exchange rate
W_1	weight of the building material	1.423 kilograms
W_2	The weight of the support material	1.209 kilograms
CM_V	Additive cost rate	98,501 kilograms / dinars
X	construction weight	1.016 kilograms
V_{MAX}	Mixing materials - supplier	67.58 kilograms
C_1	The purchase price of the machine	7,297,187 dinars
M	Machine maintenance	126,863 dinars
S	scrap	0
T	machine useful life	10 years
T_{bs}	Time required for setup and construction	4.16 hours
L_2	Technical wage cost rate	34,064 dinars / hour
$T_{Processing}$	The time required to perform tasks	4.30 hours
E	The power consumed by the machine	3 kW
T_b	construction time	3.9 hours
E_R	energy cost rate	60 kW
H_2	Industrial indirect cost rate - production	16,819 dinars / hour

Source: Prepared by the Authors

Table 4 above shows all the necessary data that are directly and indirectly involved in the parts manufacturing process. The direct costs of this stage can be easily calculated now. After calculating the costs of all elements of the production stage, the costs of this stage can be reached through the following equation (2):

$$\boldsymbol{C_{Processing} = C_{Mat} + C_{Mach} + C_{L2} + C_{OH2}} \dots\dots\dots\dots\dots\dots (\mathbf{2})$$

C_{Mat}= cost of materials required for construction
C_{Mach}= cost of the machine
C_{L2}= cost of wages
C_{OH2}= Industrial indirect costs

It can be calculated as follows:

$$= 215.4 + 132{,}849.6 + 259{,}255 + 58{,}866.5$$
$$= 451{,}187$$

The costs of wages for the activities that follow the activity of manufacturing parts, which amount to (42,750) dinars, and the indirect industrial costs, which amount to (22,640) dinars, are added to the production costs, as follows:

=22,640 + 42,750 + 451,187
=516,577

From the above, and after collecting the costs of wages for the activities that follow the manufacturing activity and the indirect costs, the production costs in the end amounted to (516,577) dinars, as after the completion of this stage, a prosthesis above the knee is fully

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obtained, after the completion of the production stage, the transition to the activities of the post-production stage.

Post Production

The last stage of the value chain. This stage begins immediately after the completion of the production stage. It includes several common activities, namely marketing, distribution and customer services.

Marketing

The center markets and promotes its products through its own page on the Facebook program, in order to display what the center is accomplishing in the manufacture of prostheses and medical supports in terms of manufacturing and developments in it, as well as communicating with customers and answering their questions through it, because the center is an economic unit Non-profit government, so it does not need marketing in order to obtain an increase in sales and profits.

Customer Service

This activity includes, after providing the prosthetic limb to the patient, several services, including training the patient to use it through the medical rehabilitation employee, compared to the prosthesis made in the traditional way, the limb made by additive manufacturing technology is lighter and more comfortable due to its conformity with measurements greatly, so it is easier It is usable and the patient can learn to use it more quickly than in conventionally manufactured limbs. The wages of service personnel not directly related to the manufacturing process are not affected by additive manufacturing technology.

Post production cost is obtained using the following equation:

$$\boldsymbol{C_{Post-processing} = C_{l3} \dots\dots\dots\dots (3)}$$

$C_{Post-processing}$ = Total post-production costs
C_{l3} = wage costs for post-production

The total cost of the above-knee prosthesis can now be calculated during the value chain stage, as follows:

$$= 476{,}459.3 + 516{,}577 + 228{,}108$$
$$= 1{,}221{,}144.3$$

Costs under Additive Manufacturing Technology and Value Chain

The following Table 5 shows a list of costs under additive manufacturing and the value chain.

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Table 5
COST PER UNIT OF AN ABOVE-KNEE PROSTHESIS PRODUCT UNDER ADDITIVE MANUFACTURING

	Details	Cost
1	Direct materials cost	5,703,610
2	Direct wage cost	18,329,447
3	indirect manufacturing costs	4,631,446
4	Administrative costs	6,921,853
5	the total	35,586,356
6	÷ the number of units produced	22
7	cost per unit	1,617,562

Source: Prepared by the Authors

It is clear from the previous table that the cost of one unit of the above-the-knee prosthesis amounted, according to the integration between the additional manufacturing technologies and the value chain, (1,617,562) dinars, which is a very low cost compared to the costs of traditional manufacturing, as the difference between them is (7,482,021) dinars (1,617,562 - 9,099,583), which This is due to the significant decrease in material and industrial indirect costs, as well as the decrease in wages in terms of costs and number.

RESULTS & CONCLUSION

1. As a result of developments in the modern industrial environment and the resulting intense competition, change and progress in production methods, openness in markets and globalization, traditional costing systems have become incapable of providing appropriate information to management and have also become inefficient in the field of cost reduction.
2. The application of additive manufacturing technology leads to a reduction in the value chain links through digital intervention, which achieves significant savings in costs, effort and time.
3. Through additive manufacturing technology, it is possible to make designs with complex geometric shapes with great ease, in contrast to what is the case in traditional techniques that depend on removing materials, which face difficulty in obtaining the required geometric shape, in addition to the great waste that occurs in materials.

Discuss the Results

1. Establishing training courses among employees on an ongoing basis in order to disseminate the concept of additive manufacturing technology among the personnel working in the center, and continuous follow-up to get rid of all kinds of waste at all levels, as well as reduce gas emissions and pollutants and save in energy and resource consumption to achieve high-quality and environmentally friendly outputs.
2. Full commitment to the working times specified for the production process and striving to delete the times that do not add value in order to avoid waste of resources, which negatively affects the performance of the center.
3. After calculating the costs of the parts to be purchased, it was found that the cost of manufacturing through additive manufacturing technology provides much more costs than purchasing it, while reducing the time for materials to arrive at the center and limiting the purchase of materials with high prices.

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