International Journal of Operations Management
ResearchLEAP

Volume 2, Issue 3, April 2022, Pages 29-42
DOI: 10.18775/ijom.2757-0509.2020.23.4004
URL: https://doi.org/10.18775/ijom.2757-0509.2020.23.4004

Investigating the Potential of 3D Printing Technology on Spare Parts Business for Supply Chain Management in Appliance Industry

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Abstract: 3D printing is a process used to fabricate three-dimensional objects based on the digitally controlled deposition of successive layers of material until a final structure is created. This research presents a case study in which two models were built to estimate the operation cost of a spare parts business for an appliance manufacturing company: a base model and an alternate benchmark model in which spare parts are supplied by the traditional manufacturing method or 3D printing. With the developed models, this research compares the total inventory cost of ownership and the number of suppliers for two supply chain management scenarios. Further, a third model (hybrid cost model) was established where spare parts are supplied partially by traditional manufacturing and partially by 3D printing according to maximize cost savings. The cost analysis from the three models concludes that the mixed model shows the best outcome for simplifying supply management complexity and ultimately reducing total cost of spare parts inventory. This case study can help appliance industries to assess and decide if 3D printing is a feasible production method for spare parts in terms of supply chain management strategy.

Keywords: 3D printing, supply chain management, spare parts supply, inventory cost

1. Introduction

3D printing, also known as Additive manufacturing (AM), is a process used to fabricate three-dimensional objects based on the digitally controlled deposition of successive layers of material until a final structure is created. 3D printing includes a family of technologies that were originally used to fabricate engineering prototypes in minimum possible lead time based on computer-aided design (CAD) and computer-aided manufacturing (CAM) models. In the early stage of this invention, due to the limitation that only soft materials such as plastics, wax, etc. can be used, 3D printing was primarily used for prototyping purposes that allow designers to review and approve concepts before companies make large investments in product development (Berman, 2012). With technological advancements in material science and engineering, 3D printing now can be used for many industries to produce real functional end-user parts with strong engineering materials including metals and ceramics. Reported by the Wohler Associates (2018), around one third of 3D printing parts were for functional part production, including Airbus, Boeing, Honeywell and GM that are exploring this business potential. The overall market growth shows that 3D printing technology is potentially becoming a critical element of future supply chains.

For OEM (original equipment manufacturing) industries, supply chain management is one key element that must be seamlessly integrated in the enterprise management roadmap in order to receive and produce superior quality products, and finally achieve business excellence. For spare parts businesses, “spare parts” are also known as “service parts, repair parts, or replacement parts”. Spare parts are items used to maintain and repair failed equipment in consumer or industrial markets (Saalmann et al., 2016). Due to its own dynamics, the primary goal is to provide consumers with a replacement part to fix failed equipment with quick delivery. Since the need for a spare part is directly tied to equipment failure (versus customer demand), it creates an uncertain, intermittent, and sporadic demand pattern in the supply chain of service parts

(Martin et al., 2010), and further creates significant challenges in managing stock levels and part quality standards (Syntetos & Keyes, 2009).

The spare parts business of OEMs, on one hand, is in general very lucrative and has profitability; On the other hand, these businesses may have a risk due to the market uncertainty. With the traditional supply chain operation ordering and carrying spare parts in batches in the warehouse, the uncertain nature of spare parts businesses could result in long lead time, long customer waiting time and then dissatisfaction, and many times could incur high inventory costs. 3D printing has a superior advantage in producing customized parts in a much faster response, which has been employed in various industries including automotive, aerospace, food equipment, medical and dental parts for various purposes. While 3D printing has been existed for more than three decades, little has been done in the spare parts business to understand the potential impact of 3D printing on supply chain management in terms of total cost of ownership and supplier rationalization, especially to the appliance industries.

2. Literature Review

Originated in mechanical design and parts manufacturing, 3D printing applications have been extended to a wide range of fields. For example, 3D printing has been employed in the medical field to produce human body parts such as knee joints and denture for implantation due to the freedom to design and customize parts in an accurate way with reasonable cost. When open source software became available in 2009, people began creating and printing objects using 3D printing technology and revealing exponential discoveries (Maxey, 2013).

In the manufacturing and manufacturing service sectors, Sasson and Johnson (2016) noted that shifting from traditional supply chain methods to 3D printing may bring substantial benefits to organizations in the forms of flexibility, quick response to demand fluctuations, and on-location production. According to Garrett (2014), this type of transformation improves responsiveness to consumers and brings more agility in the supply chain. Mohr and Khan (2015) noted that 3D printing technology promotes a shift from offshore to domestic production, which will highly impact the existing supply chain. Waller and Fawcett (2013) recognized the four disruptive characteristics of 3D printing: quality, need for less capital investment to launch a broad range of goods, shift in business model where consumers also become producers, and low economies of scale. These features will change how companies look at traditional supply chains. Similarly, Nyman and Sarlin (2014) emphasized four different aspects of 3D printing, including sustainable and green operations, flexibility, small economies of scale, and change in business model.

An extensive literature review performed by Mohr and Khan (2015) captured seven different impact areas of 3D printing on supply chain management, noting these impacts as “mass customization, changing view on resources, decentralization of manufacturing, reducing complexity, rationalization of stock and logistics, changing value adding activities and disruptive competition”. Attaran (2017) stated that being the most promising technology, 3D printing will become a core factor in the production process, affecting the road map of supply chain management. This technology transforms supply chains by consolidating manufacturing locations and logistic centers, bringing manufacturing closer to end users (Khorram & Nonino, 2016). Thomas and Gilbert (2014) discussed that, as a manufacturing method, 3D printing can reduce supply chain disruptions because it removes physical product touchpoints in a supply chain network. Production can then be localized in small manufacturing facilities using 3D printing, which reduces the risk of supply disruptions and transportation cost. This technology can also improve supply chain models due to its quick delivery time, flexibility, optimal resource usage, and overall process efficiency. Depending on specific business natures, 3D printing can be used as an alternative or supplementary supply chain method to produce parts in small batches with a “made to order” concept that allows companies to mitigate carrying high inventory levels and reduce transportation costs and further from an overall perspective, supply chain complexity could be significantly reduced (Janssen et al., 2014; Petrick & Simpson, 2013).

It has been agreed that 3D printing has a great potential to change the landscape of supply management for spare parts business in general, although 3D printing may bring varied impacts to specific industries (Holmström et al., 2010; Khajavi et al., 2014; Liu et al., 2014; Muir & Haddud, 2018). Bradshaw et al. (2010) performed a qualitative study and specified that 3D printing can be used to manufacture service and aftermarket accessory parts for laundry machines and small domestic appliances like mixers, blenders, and cameras. Muir and Haddud (2018) used an online survey to collect data from 69 participants to understand the perceived impact of 3D manufacturing on fulfillment of spare parts demand, inventory, and customer satisfaction in medical industry supply chains. Khajavi et al. (2014) studied the utilization of 3D printing technology on the service parts of military war aircrafts, and their results showed that expanding 3D printing in the spare parts supply chain was not feasible due to the high cost of 3D equipment and low speed of production. Khajavi et al. (2018) designed a mathematical cost model for scenario analysis based on a real-world case from the aircraft spare parts supply chain. Their supply chain model built upon one used in a previous study and considered personnel, material, transportation, inventory carrying, aircraft downtime, inventory obsolescence, and initial investment in AM machine depreciation and annualized cost of initial inventory production. They investigated feasibility of using AM in supply chain hub configuration for the spare parts business and their findings showed that configuring AM production in the hub model, gives better results in terms of cost efficiency. Liu et al. (2014) also investigated the impact of 3D printing in the aircraft spare parts supply chain by developing three different models, including conventional, centralized, and distributed with data gathered from literature. Their research primarily focused on the impact of 3D printing on safety stock in the aircraft spare parts supply chain, however lacking real cost data.

The literature review above provided a broad picture of how 3D printing technology was evolved in the landscape of supply chain to service parts business. The existing studies about 3D-implemented spare parts supply chain configurations mainly focus on industries where the cost of equipment downtime is significantly high, such as aircraft, construction, and medical equipment, by using methods of quality research or survey. There is a lack of practical research about implementing 3D printing technology to rationalize supplying spare parts with a total cost structure compared to traditional manufacturing. Therefore, the goal of this research was to expand upon previous studies by incorporating a cost model approach to determine the feasibility of 3D printing on supply chain management of a service parts business in an appliance manufacturing company, in terms of total cost of ownership of spare parts.

3. Methodology – The Case Study

3.1 Company background

The company in the case study is an appliance manufacturing company that wanted to explore the feasibility and impact of using 3D printing technology to produce service parts in their supply chain. At the time of the study, the company used traditional methods to procure spare parts from pre-qualified, external suppliers from around the world or from internal factories and inventory stored in a local company warehouse. The company had over 23,000 active spare parts and over 500 suppliers. Thirty-seven percent of active spare parts were purchased internally, while the remaining 63% were purchased from external suppliers. With market competition, the company has to regularly upgrade its product model; therefore, the service parts division of the company has to face the pressure caused by part overstock, obsolescence, supplier count and management, total cost increase and long lead time. With new technologies emerging, the company believed that traditional ways of manufacturing and supplying spare parts were not the best business decision and could be improved. A case study with real business data and experimental research was conducted to consider implementation of 3D printing to supply service parts in order to understand performance differences in terms of total cost of ownership and supplier count change. Figure 1 summarizes the steps of the methodology for this study.

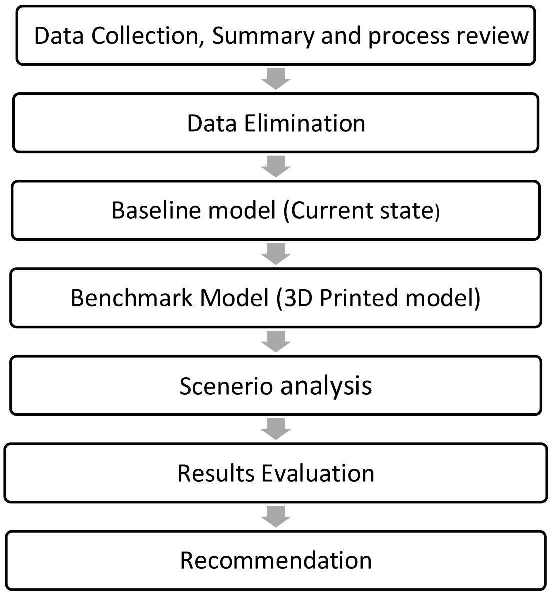

Figure 1: Activity Flow in the Research Methodology

3.2 Data Collection and Description

The target data population of this study was 23,000 active spare parts. After reviewing the master data list, due to limitations of 3D printing technology, some non-qualified parts were removed. The remaining 12,500 spare parts became the main data population of this study. The sample size of the research was limited to 100 parts due to limited time and resources. Both historical and current data were included and collected from the company's database. To protect the company's confidentiality, actual parts and supplier numbers were replaced with dummy numbers, and actual part descriptions were simplified to part families. Table 1 shows the collected data parameters and their descriptions.

Table 1: Description of Data Parameters in the Master Data File

Name	Description
Part number	Categorical data parameter, which is an identifier of a specific part design.
Part description	Categorical data parameter that describes the usage/commodity of the specific part.
Purchase price	Numerical data parameter that represents the amount of money paid to obtain the specific part.
STK Price	Numerical data parameter that represents the total cost of obtaining the specific part. Includes purchase price and all other overhead costs.
Overhead cost	Numerical data parameter that represents all fixed and variable overhead expenses.
Planner Code	Categorical data parameter that identifies the responsible materials planner of the part.
LYM	Categorical data parameter that identifies the last year the part used in mass production.
MOQ	Numerical data parameter that identifies the agreed minimum order quantity from the supplier.
LT	Numerical data parameter that represents the total lead-time of the part. Includes production and transportation times.
Setup Cost	Numerical data parameter that shows the cost charged by the supplier to set up the machine to produce the specific order for a specific part number.
Part Code	Categorical three-digit data parameter that represents the high-level categorization of the part.
Part code description	Categorical data parameter that describes the specific part code.
Product Group Code	Categorical two-digit data parameter that represents the high-level categorization of the product group.
Product group description	Categorical data parameter that describes specific product group code.

Name	Description
Part retention date	Categorical data parameter that describes the latest date the company was obligated to provide part to the consumer.
EAU	Numerical data parameter that represents the annual usage of the specific part.
Demand last 12M	Numerical data parameter that shows the number of pieces sold in the last 12 months on the specific part number.
Stock on hand	Numerical data parameter that represents the amount of physical inventory available in the distribution center of the company.
Function Part Code	Categorical data parameter that describes whether the part is functional or non-functional. A functional part means that the part is required to operate the appliance. A non-functional part means that the part does not impact the operations of the appliance directly; generally. These parts are cosmetic parts.

3.3 Research Procedure and Design

To identify, analyze, and compare the performance of the current business model with the new benchmark model, the researcher designed the framework shown in Figure 2.

Activities in each step are noted below:

- Basic data included the following parameters: part numbers, part description, supplier number, minimum order quantities, estimated annual usages, piece price, overhead cost, weight, dimensions, retention times (service lifetime), and last 24 months of demand.
- Initial data review performed to eliminate not eligible part families from the data set, such as motors, glass, electronics, etc.
- Semantic search performed on the remaining 12,546 parts to eliminate data that does not show feasibility for 3D printing due to material, technical, and size limitations. For example, parts that weigh over 500 grams are considered not suitable for 3D printing. Semantic research also helps identify parts with the most supply chain potential. Table 2 shows the results of semantic search.

Table 2: Results of Semantic Search: Categorization of Data Set by Supply Chain Potentiality

Category	Name of Category	Number of Parts	Color Zone
A	Act (Best potential)	98	Green
B	Prepare (Good potential, prepare to review)	171	
C	Follow	463	
D	Future Technical potential good, but future supply chain potential	2479	Orange
E	Technical potential, revisit supply chain data	1005	
F	Revisit technical and supply chain data	1380	Red
G	Out of scope	6950	

- From data categories A, B, and C, 100 eligible parts were selected as part of the sample size for this study. Selection criteria was based on the supply chain inspector software used from a supplier. The software ranked parts from highest supply chain improvement potential to lowest as category A highest and category G lowest (out of scope).
- Technical drawings, material specification, 3D CAD models, pictures, and part samples were collected.
- All technical data were uploaded in the 3D printing supply chain platform software.
- A base model that represents the current supply chain state with traditional manufacturing for these 100 parts was developed.
- The 100 parts are digitized and quoted using 3D printing software.
- A benchmark model was developed by using 3D printing technology obtained from the supplier's supply chain software. Price and minimum order quantity were the variables evaluated for the benchmark model.

- Analysis was performed to compare the base model with the benchmark to determine how 3D printing affects the supply chain of the service parts division in terms of supplier count, inventory cost, and total cost.

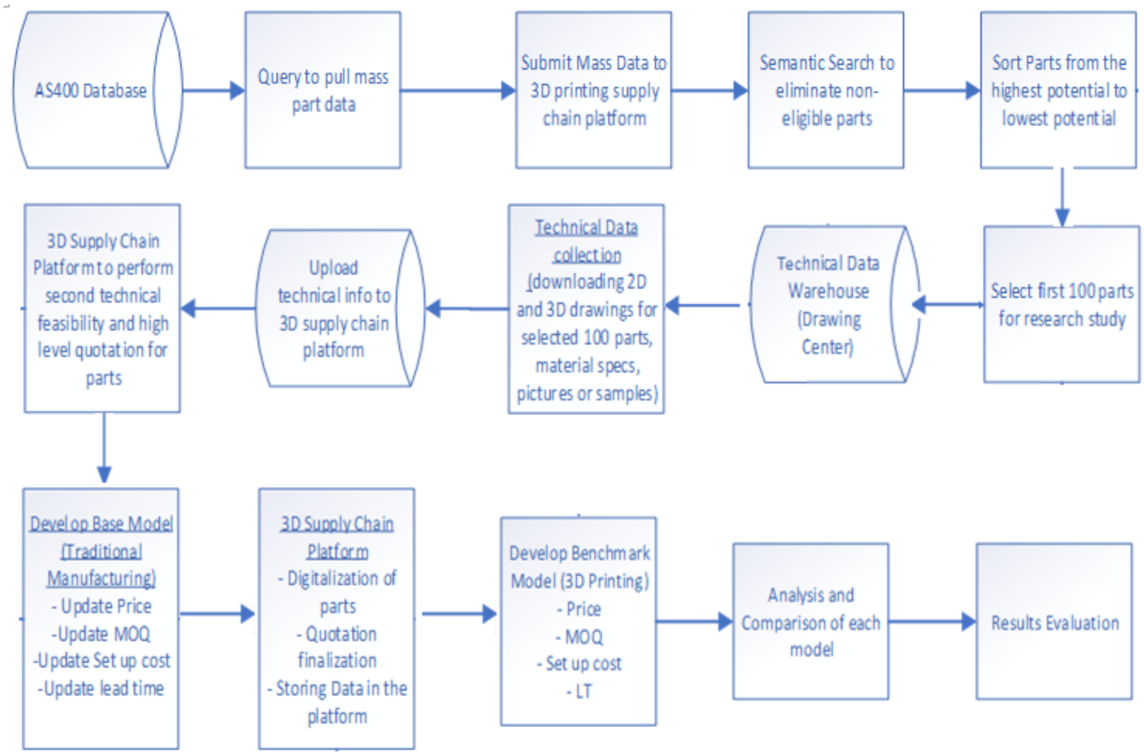

Figure 2: Research framework

3.4 Scenario Modeling

As stated previously, this research investigated the application of 3D printing in a specific business sector (appliance) with a focus on the service parts division. One hundred eligible parts with the most supply chain potential were selected as the sample size. The aim of the research was to understand whether the company could achieve better performance in terms of total inventory cost and supplier count by applying 3D manufacturing in its service parts business. To analyze and compare current business performances with the 3D printing technique, two different scenarios (models) were built. The total cost of ownership of the selected parts was compared: Scenario 1 is the base model for the supply chain where traditional manufacturing is applied and Scenario 2 is the benchmark model for the supply chain where 3D printing is used.

3.4.1 Scenario 1: Base Model

Scenario 1 is a supply chain configuration representing current, traditional manufacturing of 100 service parts. Figure 3 shows the company’s current supply practices.

Figure 3: Supply chain base model using traditional manufacturing

In the current base model, the company places purchase orders to suppliers to replenish the inventory levels of the service parts, based on pre-agreed procurement terms. Table 3 shows the main supply chain parameters used in the purchase orders placed to suppliers.

Table 3: Parameters Used for Purchase Orders

Parameter	Symbol
Part Number	PN
Supplier Part Number	SPN
Description	D
Purchase Order Number	PO
Piece Price	p
Set up cost	Setup
Minimum order quantity	MOQ
Lot Size	Spq
Order quantity	OQ
Extended purchase price (purchase cost of order)	EX
Lead time	Lt

This research study assumed that the selected sample parts (n=100) were purchased from different suppliers, where the number of supplier counts was equal to one hundred in the current (base) supply chain configuration.

3.4.2 Scenario 2: Benchmark Model (3D Printing)

Scenario 2 is a supply chain configuration where 3D printing is used as a manufacturing technology to produce 100 selected service parts based on annual demand. This model considers a simplified supply chain structure where the service parts division of the company works with only one supplier that owns 3D supply chain software and receives placed orders using the supplier's software. Figure 4 shows the supply chain configuration of service parts by adopting 3D printing. This supplier fulfills the company's orders and ships them to the company's warehouse. With the spare parts received from the 3D printing supplier, the spare parts division deploys customer orders from its warehouse. Shipping service parts directly from a 3D printing location to consumers was not considered in the scope of this study. Ordering parameters of the parts were captured in Table 3, including; part number, description, and lead time were assumed to be the same as the base model. Manufacturing lead time and its impact on the supply chain were not considered in the scope of this study.

The reasons for using this supply chain configuration are threefold: First, this configuration allowed the researcher to fulfill the research objectives in terms of total cost and complexity reduction by just focusing on comparing the total cost of the two supply configurations. Second, the company aimed to reduce complexity in its supply chain, as adding more suppliers required more time for quotation, quotation validation, and supplier validation. This would impact data reliability and increase complexity in the supply chain. Third, 3D printing tools and other technological capital investments were not in the scope of this study.

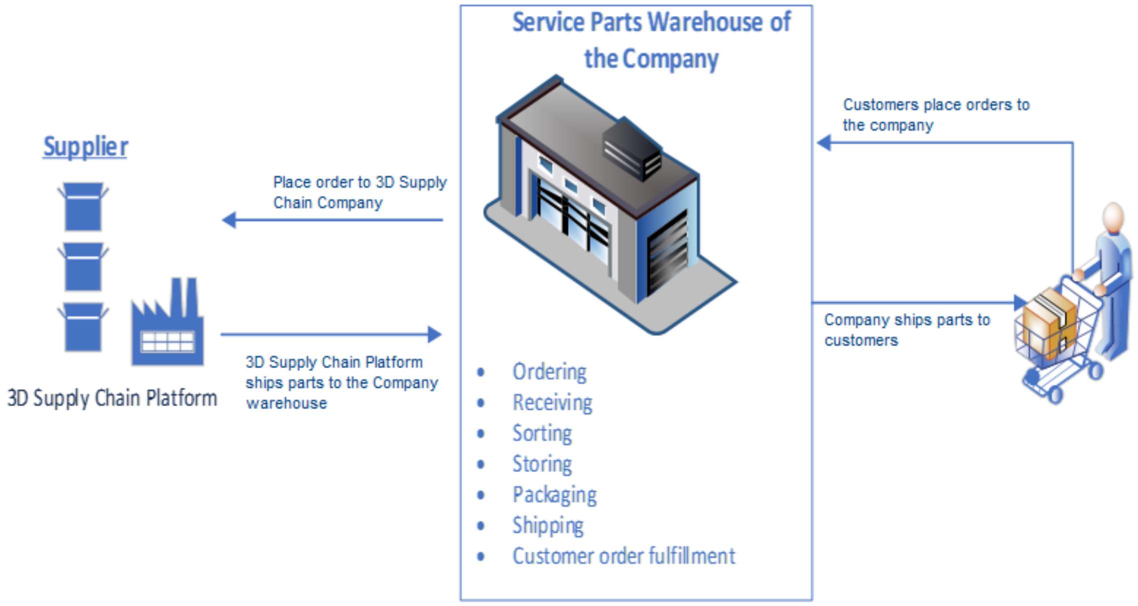

Figure 4: Supply chain benchmark model using 3D printing

3.5 Data Analysis

Based on existing studies and the scope of this research, deterministic cost modeling was used to compare the total cost of two scenarios using the following cost categories: manufacturing cost (piece purchase cost), setup cost, overhead cost, and inventory cost. Some basic rules were defined in this study:

- First, total cost calculations were based on annual part usage. Therefore, all cost parameters were calculated with an annual impact perspective.
- Second, the cost of transporting parts from suppliers to the warehouse and transporting parts from warehouse to the customers are assumed to be the same. Therefore, transportation cost and impact of lead times were not considered.
- Third, inventory costs include inventory-related costs such as capital and inventory carry-over cost (overhead) and obsolescence, which were calculated based on annual parameters.
- Fourth, it was assumed that annual part demand stayed the same for 12 months to compare variable costs of the two scenarios.

The definitions and formulas below describe each cost category and the parameters used.

Manufacturing Cost (Purchase Price): The cost parameter that suppliers charge the company to provide the manufactured spare part. This is also called the purchase price of the part. Each cost parameter is provided below.

C_{ppBase}: Purchase cost of the part from the current supply chain configuration (traditional supply chain).
C_{pp3D}: Purchase cost of the part from the proposed 3D printing supply chain configuration.

Annual Procurement Quantity (APQ): The part quantity the company needs to purchase to satisfy annual part demand. Each part comes with pre-agreed procurement parameters, including minimum order quantity and piece price. The following formula was to calculate this parameter

$$APQ = \left[\frac{EAU}{MOQ}\right] \times MOQ \tag{1}$$

Annual Spend: Cost of purchasing the part with pre-agreed order parameters with the supplier. Calculated as purchase price times annual required procurement quantity. The following equations were used to calculate annual spend for each model:

$$AS_{Base} = C_{ppBase} \times APQ$$

$$AS_{3D} = C_{pp3D} \times APQ \tag{2}$$

Setup Cost: Cost of setting up a machine to produce required parts. This was a fixed cost provided from the supplier during the quotation process that applied to each order. Not all service parts were subject to setup cost. Generally, suppliers amortize setup cost in a quotation to a company. There are cases where suppliers charge setup cost as a separate line item.

$$C_{Setup} = \text{number of orders} \times \text{setup cost} \tag{3}$$

Overhead Cost: Cost is calculated as labor for receiving, sorting, storing, picking, and packaging the service part. It also includes fixed warehouse costs like space, administration, etc. The company used a flat percentage to capture this overhead cost for each part and calculated at 13.8% of the purchase price of the part. To be consistent with the company's financial approach, the same percentage was considered in this research study. The following equations were built to calculate annual overhead cost.

$$C_{OHBase} = AS_{Base} \times 0.138$$

$$C_{OH3D} = AS_{3D} \times 0.138 \tag{4}$$

***Annual Leftover Inventory Quantity (ALINQ)**:* The leftover inventory after 12 months of usage. The following equations were used to calculate this parameter:

$$ALINQ = APQ - EAU \tag{5}$$

Inventory Carry Over Cost:_ The cost of holding inventory of unsold parts after 12 months (annual). Cost of capital and overhead cost of transferring leftover inventory to the following year were considered part of total inventory cost calculations. The company took 9% as the average interest rate to calculate cost of capital, 2% as the average cost of obsolescence, and 13.8% of the value of left-over inventory were considered to calculate inventory carry over cost. The following equation shows the calculation of this cost parameter:

$$Inv_{Carryoverpercentage} = (0.138 + 0.09 + 0.02) = 0.248$$

$$C_{invBase} = \left(ALINQ \times CppBase \times (0.248)\right) \tag{6}$$

Based on the described rules and above mathematical equation explanations, the total cost includes part cost, setup cost, overhead cost and inventory carry over cost, and the following mathematical formulations of cost models for the two different supply chain configurations were developed:

$$TC_{Base(i)} = \sum_{i=1}^{n=100} \left(C_{ppBase(i)} \times \left[\frac{EAU_i}{MOQ_i}\right] \times MOQ_i\right) + \sum_{i=1}^{n=100} (n_i \times Setup_i) + \sum_{i=1}^{n=100} \left(C_{ppBase(i)} \times \left[\frac{EAU_i}{MOQ_i}\right] \times MOQ_i \, x \, 0.138\right) + \sum_{i=1}^{n=100} (ALINQ_{Base(i)} \times C_{ppBase(i)} \times 0.248)$$

$$TC_{3D(i)} = \sum_{i=1}^{n=100} \left(C_{pp3D(i)} \times \left[\frac{EAU_i}{MOQ_{3D\,(i)}}\right] \times MOQ_{3D(i)}\right) + \sum_{i=1}^{n=100} \left(C_{pp3D(i)} \times \left[\frac{EAU_i}{MOQ_{3D\,(i)}}\right] \times MOQ_{3D\,(i)} \times 0.138\right) + \sum_{i=1}^{n=100} (ALINQ_{3D(i)} \times C_{pp3D(i)} \times 0.248)$$

Applying the two cost models with the company's data leads to \$64539.74 and \$55148.02 for the traditional supply chain model and for the supply chain model using 3D printing, respectively, shown in Figure 5. Their breakdown of total cost is shown in Table 4 and in Figure 6.

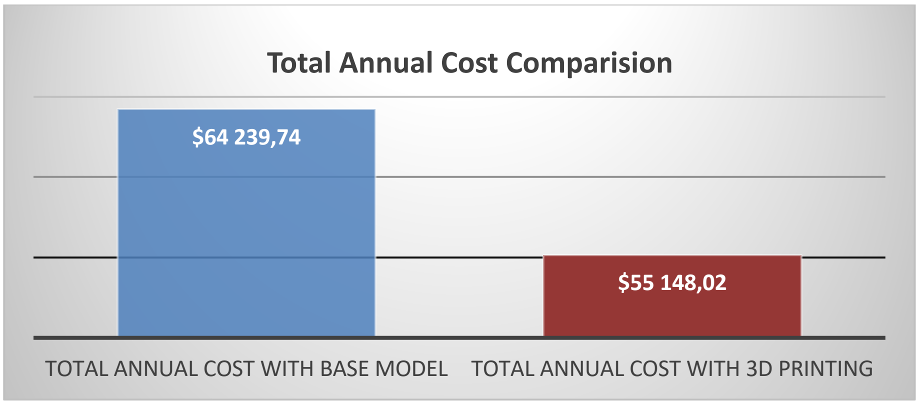

Figure 5: Total Annual Cost Comparisons.

Table 4: Breakdown of Total Cost (Comparison of the Models)

Total Cost Breakdown		
	Base Model	**3D Printing Model**
Cost Category		
Total Annual Purchase Spend	$ 50,001.03	$ 48,460.48
Total Annual Overhead Cost	$ 6,900.14	$ 6,687.55
Total Annual set up cost	$ 429.00	$ 0
Inventory Carry Over Cost	$ 6,909.57	$ 0
Left over inventory overhead	*$ 3,844.84*	$ 0
cost of capital	*$ 2,507.50*	$ 0
cost of obsolescence	*$ 557.22*	$ 0
TOTAL COST OF OWNERSHIP	**$ 64,239.74**	**$ 55,148.02**

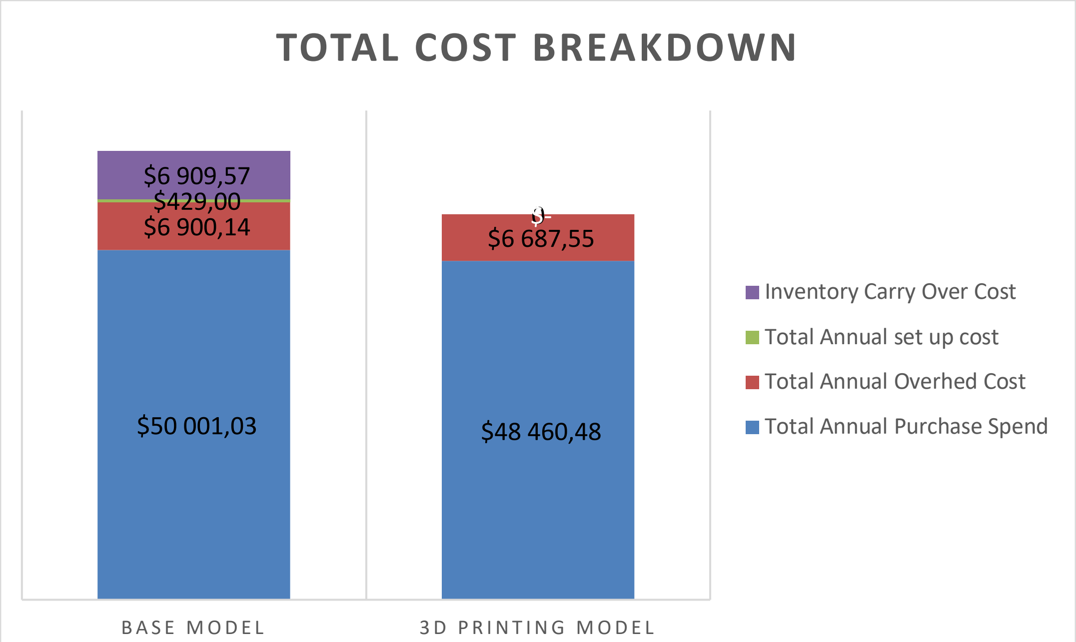

Figure 6: Breakdown of Total Cost for the two supply chain models.

Based on the total cost analysis, 49 out of 100 parts showed cost savings using 3D printing versus the traditional manufacturing method, as buying these parts using the traditional way is more costly than buying with 3D printing. Because of that, the parts are categorized as “3D printing preferred.” The remaining 51 parts showed a cost increase if using 3D printing; therefore, the parts are categorized as “Traditional manufacturing preferred.” Table 5 and the corresponding Figure 7 show a summary of the data analysis in terms of total cost and cost difference between models for each part.

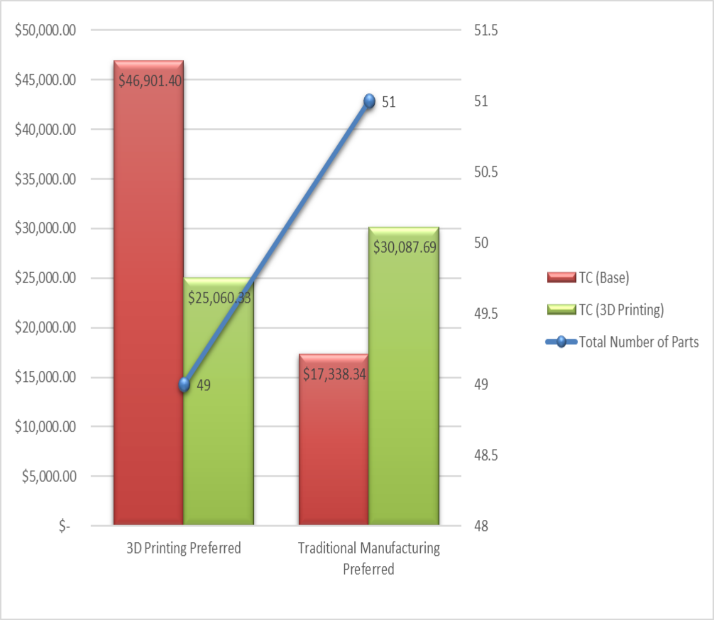

Figure 7: Summary Cost Analysis of Data Set

Table 5: Summary Cost Analysis of Data Set

Preferred Production Method (Based on TC Delta)	**Number of Parts**	**TC (Base)**	**TC (3D Printing)**	**TC (Difference)**
3D Printing Preferred	49	$ 46,901.40	$ 25,060.33	$ (21,841.07)
Traditional Manufacturing Preferred	51	$ 17,338.34	$ 30,087.69	$ 12,749.36
Grand Total	**100**	**$ 64,239.74**	**$ 55,148.02**	**$ (9,091.71)**

Given the advantages brought by the 49 parts categorized as “3D printing preferred”, the total cost of a hybrid model is created, in which 49 preferred parts are supplied in 3D printing and 51 non-preferred parts are supplied in traditional manufacturing. The hybrid cost analysis is shown in Table 6 and Figure 8.

Table 6: Summary of Total Cost of Ownership (TCO Summary)

Preferred Production Method	**Number of Parts**	**TCO (Base Model) - All Parts**	**TCO (3D Printing)- All Parts**	**TCO (Based on Preferred Method)**
3D Printing Preferred	49	$46,901.40	$25,060.33	$25,060.33
Traditional Manufacturing Preferred	51	$17,338.34	$30,087.69	$17,338.34
Grand Total	100	$64,239.74	$55,148.02	$42,398.67

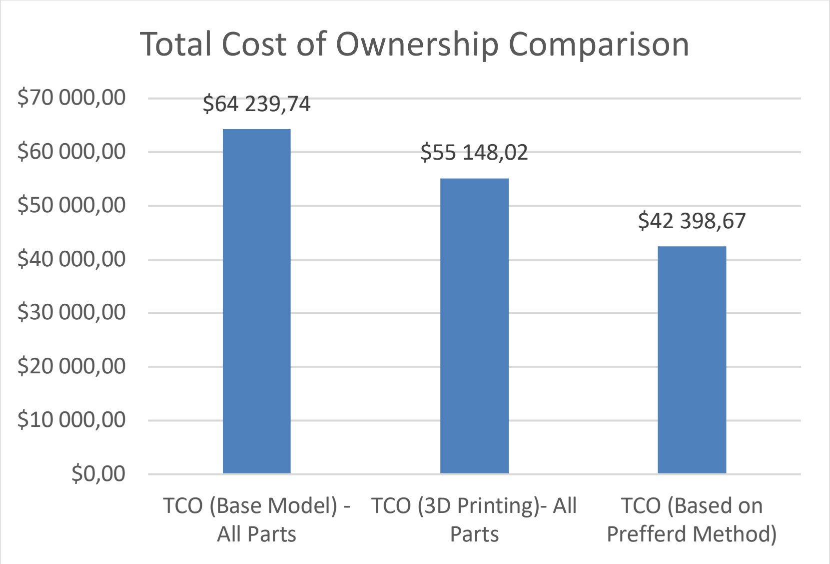

Figure 8: Total Cost of Ownership Comparison

3.6 Supplier Rationalization

Supplier rationalization is a process where companies reduce the number of active suppliers in their supply chain. The goal of this process is to help companies combine spending to fewer suppliers, which reduces complexity and creates leverage to drive better value from the supply base. Table 7 shows supplier count, percentage of supplier reduction, and total annual cost of owning the 100 parts for each model. Adapting 3D printing fully in the supply chain (that is, having 100 parts procured using 3D printing) will reduce the company's active suppliers from 100 to 1, which is a 99% reduction in supplier count with total annual cost reduction $9,090 (14% reduction). With utilizing a hybrid method (where 51 parts are purchased using traditional methods and 49 parts from 3D printing), total cost savings increases to $21,841.07 (34%), along with the supplier count reduced from 100 to 52, which is a 48% reduction compared to the company's base model. Therefore, the hybrid model would be the most beneficial in terms of economic savings and also reasonable for supplier count management. In summary, the modeling results show that using a 3D printing supply chain platform in the business model helps the company significantly reduce the active number of suppliers. Therefore, 3D printing showed a positive impact on supplier rationalization.

Table 7: Total Annual Cost vs Supplier Rationalization by Supply Chain Configuration

Supply Chain Configuration	Total Number of Suppliers	Total Annual Cost	Percent Supplier Count Reduction
Current State (Traditional Manufacturing)	100	$64,239.74	0
Benchmark Model (3D Printing)	1	$55,148.02 (14%	99%
Hybrid Model (3D + Traditional Mixed)	52	$42,398.67 (34%)	48%

4. Conclusion

The purpose of this research was to examine the feasibility of using 3D printing as an alternative manufacturing technology to produce spare parts and determine the impact on supplier rationalization in supply chains. Using case study this study investigated and demonstrated the provision of spare parts in the spare parts division of an appliance manufacturing company. Conclusions were drawn as below:

First, a cost model in terms of the total cost of ownership was built to simulate the spare parts that are produced from the traditional manufacturing supply chain or the 3D printing platform supply chain. Applying the real data collected from an appliance manufacturing company's supply chain database, the study results of this research suggest that 3D printing has much potential in supplying spare parts for this appliance manufacturing company in terms of cost savings, inventory reduction, and supplier rationalization. From this case study, it is concluded that procuring parts solely using a 3D printing platform can bring a 14% reduction on total cost compared to the current traditional supply chain. In addition, from a supplier rationalization perspective, the number of suppliers can be reduced by 99% using a 3D printing supply chain.

Secondly, a hybrid model for the spare parts supply chain was explored, using 3D printing for the 49 (3D printing preferred) parts and a traditional supply chain for the other 51%, when the two supply chain methods show cost advantages. Analysis results showed that cost savings increased from 14% to 34% for the 100 parts. This also meant a 48% supplier reduction using a hybrid model.

Thirdly, the case study analysis reveals that the hybrid model is a better fit for the industry because it makes full use of the advantage of each supply chain technology and can help achieve the maximum profit. This study also concluded that implementing 3D printing in the appliance spare parts creates flexibility in supply chain management where organizations can reduce the total cost and complexity by rationalizing the number of suppliers in the supply chain.

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