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Additive manufacturing in offsite repair of consumer electronics

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Abstract

Spare parts for products that are at the end of their life cycles, but still under warranty, are logistically difficult because they are commonly not stored in the central warehouse. These uncommon spare parts occupy valuable space in smaller inventories and take a long time to be transported to the point of need, thus delaying the repair process. This paper proposes that storing the spare parts on a server and producing them with additive manufacturing (AM) on demand can shorten the repair cycle by simplifying the logistics. Introducing AM in the repair supply chain lowers the number of products that need to be reimbursed to the customer due to lengthy repairs, improves the repair statistics of the repair shops, and reduces the number of items that are held in stock. For this paper, the functionality of the concept was verified by reverse engineering a memory cover of a portable computer and laser sintering it from polyamide 12. The additively manufactured component fit well and the computer operated normally after the replacement. The current spare part supply chain model and models with AM machinery located at the repair shop, the centralized spare part provider, and the original equipment manufacturer were provided. The durations of the repair process in the models were compared by simulating two scenarios with the Monte Carlo method. As the biggest improvement, the model with the AM machine in the repair shop reduced the duration of the repair process from 14 days to three days. The result points to the conclusion that placing the machine as close to the need as possible is the best option, if there is enough demand. The spare parts currently compatible with AM are plastic components without strict surface roughness requirements, but more spare parts will become compatible with the development of AM.

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Keywords: Additive manufacturing; 3D printing; digital spare parts; supply network; Monte Carlo simulation

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1. Introduction

Outsourced offsite repair warranty, also known as carry-in warranty, is commonplace in consumer electronics and means that the product needs to be taken to companies specialized in warranty repairs appointed by the original equipment manufacturer (OEM), as opposed to onsite repair warranty, in which the technician repairs the defective device wherever the customer is located. (Taylor 2007; Prabhakar Murthy & Blischke 2006)

Nomenclature

AM	Additive manufacturing
OEM	Original equipment manufacturer
MSC	Maintenance service contract
SKU	Stock-keeping unit
TAT	Turnaround time

To maintain the level of speed and quality of the repair of their devices, OEMs have maintenance service contracts (MSC) in place with companies that take care of their warranty repairs, henceforth referred to as repair shops. The MSCs obligate the repair shops to perform a certain percentage of repairs in a limited amount of time. The duration of repair is measured with Turnaround Time (TAT), which starts when the device is registered at the repair shop and stops when the device leaves the repair shop. The amount of work days necessary to fulfill the MSC conditions is often tightly calculated to include the diagnostics, spare part delivery, repairs, and testing of the products. As such, offsite repairs are relatively rigid and well controlled processes. In return for the services, the OEMs provide the repair shops with spare parts and pay per repaired device or a lump sum for the services provided during a certain period. The spare part distribution is often handled by separate companies that acquire spare parts from the OEM and distribute them to several repair shops. (Kurvinen et al. 2016; Dometic 2016; Prabhakar Murthy & Jack 2014)

As the acceptable number of days in repair is tightly set, the repair shops face sanctions if too many of their repairs fall behind that number of days. For this reason, it is a significant problem when a repair shop receives a device that has entered its end-of-life but is still under warranty. These devices rarely have spare parts readily available in the central warehouse of the spare part distributors. The spare parts must be sourced from smaller warehouses or from the OEM resulting in potentially very long delivery times. The repair can also be delayed if a technician performs a misdiagnosis or orders the wrong part, in which case the waiting time can be extended twofold. Alternatively, the plastic in consumer electronics tends to become brittle with age and a part can break during the repair procedure through no fault of the technician. In these cases, the repercussions of an extended repair process are inflicted upon three parties: the repair shop faces sanctions because it cannot fulfill the performance level required by the MSC, the consumer must wait longer for their unit to be repaired, and the OEM suffers image loss. To aid in this issue, the spare parts that can cause delays in the repair process could be additively manufactured.

The use of additive manufacturing (AM) in supply chains has been researched extensively in recent years. It has been shown to offer radical advantages in flexibility, savings in inventory management, and shorter delivery times. (Holmström & Partanen 2014; Sasson & Johnson 2016; Oettmeier & Hofmann 2016; Gebler et al. 2014; Mellor et al. 2014; Chen 2016). As a subset of the implementation research, the use of AM in spare parts applications has been researched with favorable results (Liu et al. 2014; Khajavi et al. 2014). According to the research of Khajavi et al., the most promising way of using AM in spare parts is to store 3D files on a server and download them for use per need. The question of the location of the AM machine appears in many research papers. In the case of this study, the machine could be placed in the repair shop, the spare part provider warehouse, or in the OEM manufacturing network.

Using AM in an offsite warranty repair supply chain could minimize outliers and make the TAT in the repair process more uniform. The introduction of AM in the supply chain of the spare parts would potentially reduce the TAT of repairs from weeks to days in specific cases. Additionally, the spare parts provider would benefit from reduced warehousing and logistics costs because the number of stock-keeping units (SKUs) to keep in stock would be lowered. Moving spare parts to the cloud would also enable the spare part providers to get rid of spare parts that spend years in storage without demand.

The actors within the supply chain of offsite warranty repairs include the customer, the repair shop, the spare part distributor, and the OEM. The process starts when the customer delivers the device to a repair shop, where the defect is diagnosed and a necessary spare part is ordered from the spare part distributor. The spare part distributor, in most cases, has the spare part in stock and can send it to the repair shop to be replaced, after which the repaired device is sent on to the customer. In a minority of cases, however, the spare parts are not found at the central warehouse and need to be sourced from other locations of the spare part distributor or from the OEM network. This process can last weeks, consequently delaying the repairs considerably. The current model (a) of a warranty repair supply chain is represented in Fig. 1. In the presented models, solid arrows represent the movement of objects and dotted arrows represent movement of information.

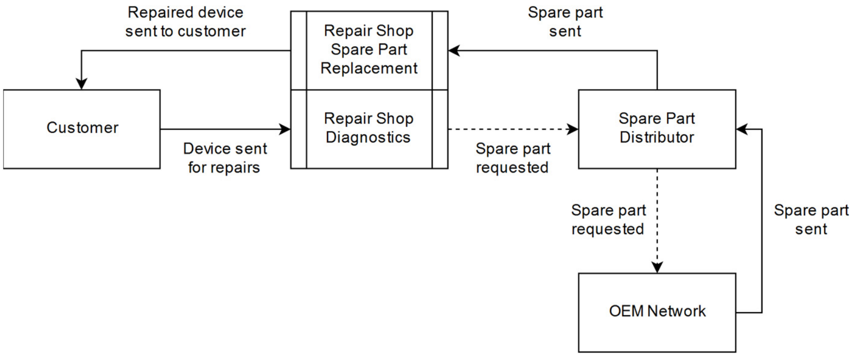

Figure 1. Current model of a warranty repair supply chain (a).

The purpose of this study is to investigate if acceptable spare parts can be produced with AM and to compare the performance of the current model of the supply chain with three proposed models that include AM in different parts of the supply chain.

2. Methods

The viability of using additive manufacturing to produce consumer electronics spare parts was verified by additively manufacturing a potential spare part. The spare part was chosen based on available technologies and consumer electronics devices. The chosen part was a memory cover of a Dell Latitude 4300 portable computer that can crack when performing repairs. The memory cover is a suitable candidate to be manufactured additively because its size allows it to fit into most build chambers of AM machinery and because it is located at the bottom of the portable computer, which makes minor differences in material and color more acceptable.

The part was measured with a caliper and 3D modeled with Creo 3.0 M050, manufactured in EOS EOSINT P 395 from Polyamide 12 material with a layer thickness of 0.1 mm, and submerged in black dye to correspond with the rest of the components of the Dell 4300. The CAD model of the memory cover is presented in Figure 2.

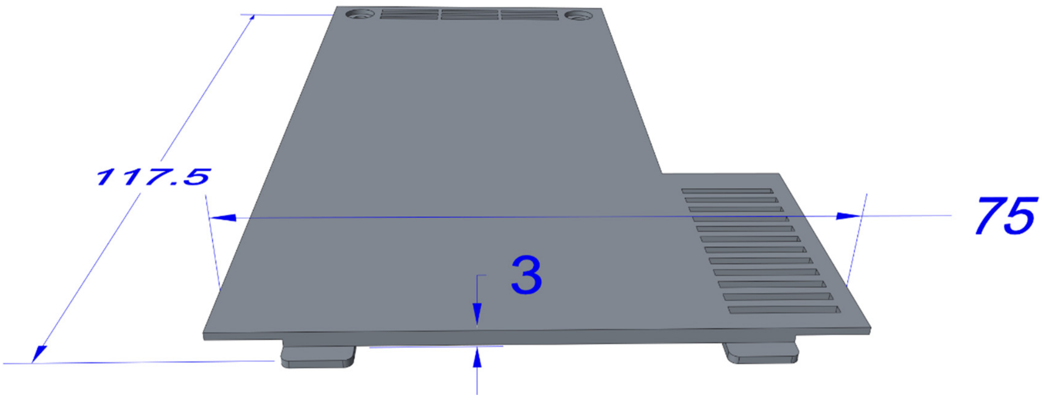

Figure 2. CAD model of the memory cover with dimensions in millimeters

The laser-sintered part was attached to the computer using the screws from the original memory cover. A stress test was performed to test the part for temperature compatibility by running Intel Burn Test 2.54 for 48 hours.

Once the functionality of the part is verified, the effect of AM on the supply chain needs to be examined. This is done by presenting the current supply chain model of an offsite warranty repair process along with three conceptual designs of supply chains involving AM. In the first proposed model (b), shown in Fig. 3, an AM device capable of producing spare parts is placed at the spare part distributor. In this case, the lengthy spare part procurement loop can be avoided by manufacturing the spare part on the spot, if the spare part fulfills the requirements set by the AM machinery.

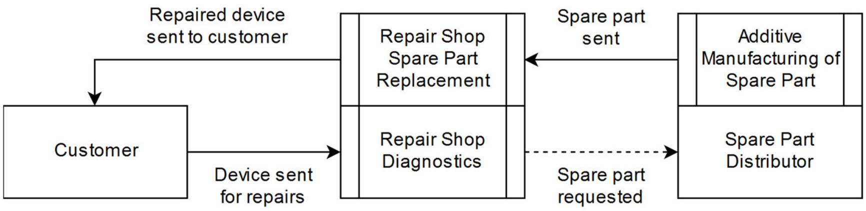

Figure 3. Model of a supply chain “AM at spare part distributor’s premises” (b).

In the second proposed model (c), shown in Fig. 4, the AM device is placed in the repair shop. In this case, the spare part is requested normally, but when the distributor notices that it does not have the requested spare part in stock, it sends 3D files to the AM device instead. This process can be automated so that it happens instantly.

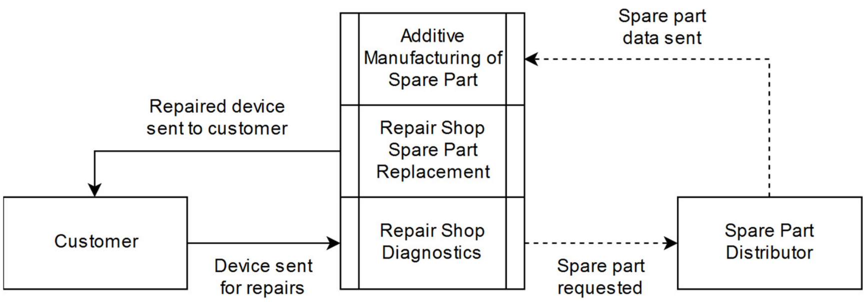

Figure 4. Model of a supply chain “AM in repair shop” (c).

In the third proposed model (d), shown in Fig 5, the AM device is placed as a part of the OEM's manufacturing capacity.

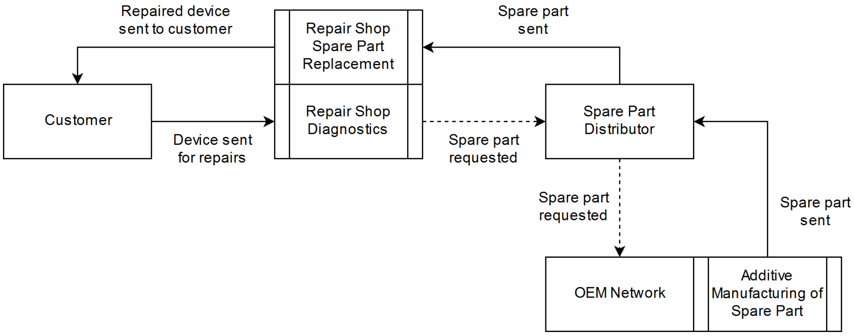

Figure 5. Model of a supply chain "AM in the OEM network" (d).

To evaluate the performance of the presented supply chain models, the average duration of repairs and their distribution for each scenario and model combination need to be obtained. This is done with the Monte Carlo method by simulating two scenarios based on typical industry cases:

Scenario 1: A device is brought in for replacement of a plastic component that is not in stock

Scenario 2: A device is brought in for repairs of an electronic component that is in stock, but a plastic component that is not in stock is damaged during repairs and must be replaced

Several assumptions were introduced in the simulation of the supply chain scenarios. The TAT begins when the device is received at the repair shop and stops when the device leaves the repair shop. The diagnosis of the device can happen immediately at arrival or can take up to two days. The spare part is requested immediately at the end of the diagnosis. The spare part distributor handles the spare part requests automatically, which means that the process is instant. The delivery time from the secondary location or OEM to the spare part distributor is between five and ten days. The delivery time from the spare part distributor to the repair shop is between two and four days. The AM of a spare part at the spare part distributor takes between one and three days. The AM of a spare part at the repair shop can happen within the same day or can take up to two days. The AM of a spare part at the OEM facility takes between one and three days. The replacement process of the spare part at the repair shop can happen within the same day of receiving the spare part or last up to one day. All durations of the ranges mentioned have the same probability.

The models of the supply chains and the assumptions made in scenario simulations are based on extensive work experience in the field of consumer electronics warranty repair of the first author.

3. Results

The spare part was manufactured successfully and was attached to the bottom of the computer with the screws from the replaced original cover. The part fit without an issue and the computer operates normally. A stress test was completed without failure and there was no deformation of the laser-sintered part. The part attached to the Dell Latitude 4300 is shown in Figure 6.

Figure 6. Laser sintered plastic cover (middle) attached to a Dell Latitude 4300 portable computer.

The average TAT of each scenario and model combination results of the Monte Carlo simulations were collected in Table 1.

Table 1. Collected results of average TAT in scenario/model Monte Carlo simulations, 1000 iterations.

Scenario	Current model (days)	AM at distributor's premises (days)	AM in repair shop (days)	AM in OEM's network (days)
1	14	7	3	15
2	17	11	7	18

Models b and c resulted in decreased TATs, while model d increased the duration of the repair process. The most notable decrease in TAT is for scenario 1 in model c, where the TAT drops from 14 days to three days. The percentage of repairs surpassing the TAT thresholds of five and ten days in each model and scenario combination are presented in Table 2. While the TAT threshold in MSCs varies from contract to contract, five and ten days (i.e. one or two business weeks) are indicative of certain levels of repair speed and can be used to present the potential of each model.

Table 2. Percentage of repairs exceeding example TAT thresholds in scenario/model Monte Carlo simulations, 1000 iterations.

Scenario, TAT threshold	Current model (days)	AM at distributor's premises (days)	AM in repair shop (days)	AM in OEM's network (days)
1, 5 days	100	78.8	0	100
1, 10 days	95.8	0	0	96.9
2, 5 days	100	100	71.4	100
2, 10 days	99.9	51.2	0	100

Models a and d performed poorly in both scenarios, with 100 % of repairs surpassing the five-day limit for both scenarios, and 95.8 % to 100 % surpassing the ten-day limit. The performance of model b was considerably better for the ten-day threshold, with 0 % late repairs in scenario 1 and 51.2 % in scenario 2. The five-day limit was still problematic for model b as 78.8 % surpassed the threshold in scenario 1 and 100 % in scenario 2. Model c has 0 % late repairs in all combinations except for the five-day threshold in scenario 2, in which 71.4 % of repairs surpass the threshold.

4. Discussion

The largest improvement in TAT is seen in scenarios 1 and 2 in model c. This is because it is most beneficial to place an AM machine closest to the point of need, thus eliminating unnecessary logistics. The most beneficial solution is to place the AM machine in each repair shop. However, the demand in these repair shops should be high enough to justify the acquisition costs and operating costs of the machine. For the spare part distributor, it is easier to justify the cost of the machine because the demand is necessarily higher, since the parts are distributed to several repair shops. Placing the AM machine in the OEM network would bring flexibility to the OEM because they would not need to stock certain parts, but it makes the repair process longer. The effects of the different supply chain models are shown in Table 3.

Table 3. Comparison of effects on actors between models.

Actor	Current model	AM at distributor's premises	AM in repair shop	AM in OEM's network
Customer	Long absence of device	Shorter absence of device	Shorter absence of device	Long absence of device
Repair shop	Long TAT	Reduction in TAT	Reduction in TAT; investment in AM machinery	Long TAT
Spare parts distributor	Maintaining large inventory and complex distribution network	Lower warehousing costs; investment in AM machinery	Lower warehousing costs	Lower warehousing costs
OEM	Slow repairs damage brand	Faster repairs improve brand	Faster repairs improve brand	Slow repairs damage brand; investment in AM machinery

The results of the scenario simulations are promising and placing AM machines in warranty repair supply chains should be considered. In addition to the benefits listed above, the reduced logistic emissions cause the reduction of the carbon footprint of the entire supply chain. However, due to the restrictions of AM, only certain components can be produced. In consumer electronics, these are limited mainly by material and surface quality. In practice, only plastic components that do not require a specific finish are good candidates for AM production of consumer electronics spare parts. Although this is a severe limitation, numerous components are compatible with an AM supply chain. This is especially true for internal parts inside consumer electronics that can look and feel different from the rest of the assembly because they are not seen by the user under normal circumstances.

Producing metal parts for consumer electronics, such as hinges of portable computers, would be a great advantage, but this is currently prohibitive due to the high costs of acquiring and running the machinery, and necessary expertise of verifying the manufacturability of metal parts. The type of AM machine to be used depends on where it would be placed. If the machine is to be placed in the repair shop, it should be easy to use and office friendly because a repair shop environment is not meant for manufacturing. Additionally, the machine should be able to produce one part very quickly due to the sporadic demand. Fused deposition modeling would be the optimal technology for an AM machine in this case because its production time scales quite linearly with the amount of parts being manufactured and it can be used with minimal training (Brajlih et al. 2011).

If the AM machine is placed in the spare part distributor's warehouse, it can require more expertise and dedicated space because the spare part distributor has resources and motivation to introduce small-scale production in their premises if it proves profitable enough. Because spare parts providers service several repair shops, their demand for rare parts is quite steady. Therefore, the AM machine implemented at the spare part distributors could be of the laser sintering or stereolithography variant. Laser sintering and stereolithography benefit greatly from producing multiple parts at once and their production time per part is lower the more parts are being produced. If the OEM wants to include AM in its production processes, it should likewise consider laser sintering or stereolithography.

5. Conclusions

Supply chain models of offsite warranty repairs involving AM were introduced and simulated and a spare part was additively manufactured and successfully tested. It is evident from the results of this study that AM would benefit all the actors in the supply chain and should thus be given serious consideration. Although AM can be used to manufacture only a small portion of the necessary spare parts, it would considerably reduce the TAT of certain repairs. In addition, more parts are bound to become viable in the future with the rapid advance of AM.

The AM machine should be placed as close to the spare part requirement as possible, while also considering the level of demand in profitability calculations. Placing the AM machine at the spare part provider or at the repair shop can shorten the repair cycle significantly, reduce warehousing costs for the spare parts distributor, and improve the brand reliability of the OEM. In contrast, placing AM machinery at the OEM manufacturing plants brings the advantage of flexibility to the OEM but does not improve the performance of the supply chain.

The introduction of AM in offsite warranty repair activities requires the cooperation of all the actors of the supply chain. Therefore, the OEMs, spare part distributors and repair shops should jointly investigate the possibilities, responsibilities and logistics of using AM to improve their supply chains.

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