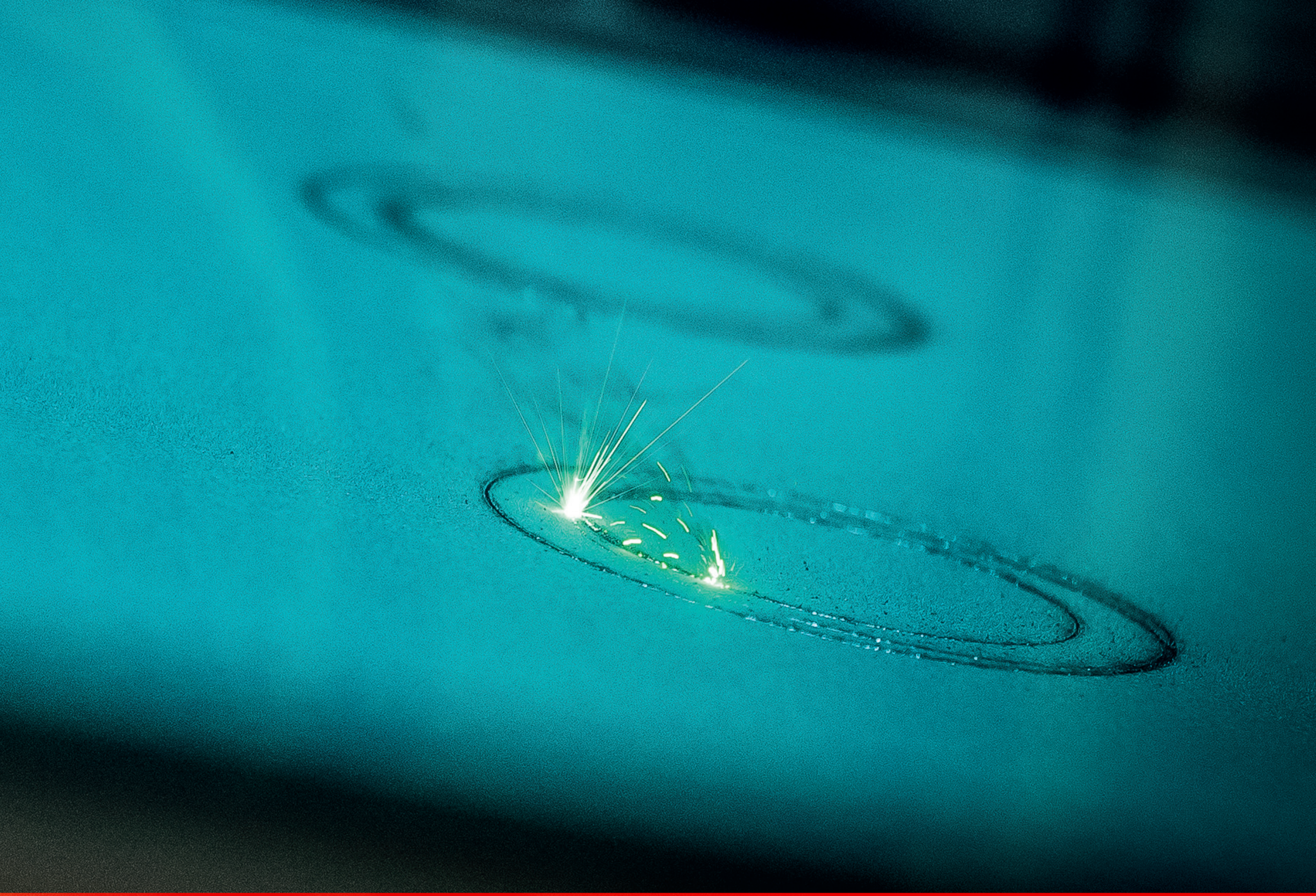

The Potential of **Additive Manufacturing for Service Logistics**

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Preface | Four years of evaluating the potential of Additive Manufacturing

What if an army on a mission in Mali could print a spare part for a broken jeep right there on the spot? After all, storing spare parts in a camp situation is difficult, expensive, and sometimes even impossible. It's also a challenge to get spare parts to such remote locations in time for them to be of any use. And suppose that – in whatever industry – you would like to repair your machinery but the manufacturer is no longer making spare parts: could 3D printing be the solution? And what about the potential of Additive Manufacturing (AM), as 3D printing is also known, for repairing parts or creating temporary replacements for parts with long delivery times when downtimes need to be kept as short as possible? The SINTAS research project – Sustainability Impact of New Technology on After-sales Service supply chains – provides answers to these questions.

In the period 2014-2019, scientists from the University of Twente and Eindhoven University of Technology carried out research in close co-operation with the Dutch Ministry of Defence, Fokker Services, NLR – Netherlands Aerospace Centre, Thales Netherlands, Additive Industries, and Dinalog. The main topic was the potential that AM offers for spare part logistics.

Two PhD students at the University of Twente and one at Eindhoven University of Technology conducted the research. Matthieu van der Heijden, associate professor in the Department of Industrial Engineering and Business Information Systems at the University of Twente, led the project. Tiedo Tinga, professor of Dynamics-Based Maintenance, was also involved at the University of Twente, as was Rob Basten, associate professor in the Operations, Planning, Accounting & Control research group at Eindhoven University of Technology. Both of them led work packages.

This brochure gives the most important SINTAS outcomes. We heartily recommend the knowledge that SINTAS has delivered to professionals who see the potential of 3D printing for after-sales and service logistics in various societal sectors.

Ben Gräve
Service Logistics Forum

Looking back at SINTAS | Feasibility and attractiveness of Additive Manufacturing

Matthieu van der Heijden

Tiedo Tinga

Rob Basten

Additive Manufacturing (AM) is an interesting technology for enhancing spare parts management. For example, if it becomes possible to print components on demand and on location – wherever and whenever wanted – large stocks will no longer be needed. Matthieu van der Heijden, Tiedo Tinga, and Rob Basten look back at SINTAS and its results.

Spare part inventory levels tend to be very high when asset downtime is costly or yields safety risks. This is due to the large range of parts available, including 'slow movers' with long replenishment lead times. Tinga: 'At the end of an asset's life cycle, many leftover parts are discarded. On the other hand, part shortages may occur if suppliers cease production. AM offers the flexibility to deal with such issues, as it is suitable for one-off manufacturing with a much shorter lead time.' Van der Heijden adds: 'If you only have to replace a valve on a wheel you don't want to have to buy a whole new wheel, which will end up unused and thrown away except for that small valve. AM facilities are pretty generic, so parts can be produced at many locations. AM can also reduce repair lead times for complex spare assembles that cannot be printed, as it is possible to print components needed for repair. Another potential lies in printing a part as temporary solution, or using AM to restore the worn-out pieces of a part that would otherwise be discarded.'

Useful insights | All these benefits are heavily dependent on a part's characteristics and the business situation. It is a challenge to find the parts in a large assortment that offer the most potential. Van der Heijden: 'So in SINTAS we developed a selection method for identifying the parts that may benefit from a supply chain perspective rather than just a product design perspective. In addition, several quantitative models have been developed to provide insights into both when and how AM technology could be used, or combined with conventional manufacturing methods to improve the efficiency of service logistics.' Tinga: 'Other research results included insights into the properties of the metal powders used and the parts produced with them.' Basten: 'And SINTAS also gave new insights in the benefits of printing at remote locations and in new business models that follow on from intellectual property licensing by component manufacturers.'

Promising research directions | Looking back, Van der Heijden concludes that much has been learned on the potential of AM in after-sales service supply chains. 'We discovered some promising new directions to explore, such as the combination with predictive maintenance.

Case studies revealed that there are also data issues to be resolved. For example, information on the failure behavior of AM parts is limited, and expert opinions may point in different directions. It's also not easy to estimate the costs involved in AM. Costs are expected to decline in the future, but the speed of decline is difficult to forecast. In addition, technological developments – such as new materials that might be used for AM – create uncertainty. A solution for part certification, which is a key issue in aviation, is required. Finally, Intellectual Property (IP) is an issue.'

Much to be gained from AM | Rob Basten: 'At the moment AM is of particular importance to parties that are responsible for maintenance, and indirectly for the users of the systems as well. In particular, this technology will help sectors in which systems must remain functional in remote locations. So not just things like military missions, but space travel, offshore, and mining. The producers (OEMs) will have to adjust their business models thanks to the influence of developments in AM. If they already sell service contracts, AM could become part of those. Currently, many companies view AM with a predominantly technical eye – for instance, it gives the possibility of redesigning parts. But they should also consider the entire supply chain: there is much more to be gained with AM.' For the near future, the researchers envision a form of service in which producers sell a CAD drawing that can be used only once for a 3D printing session. The researchers also encountered the Norwegian startup Fieldmade, which is working on a mobile container with printers and expert staff that can be temporarily relocated to the site of assets in project-based deployment situations such as military missions. So AM is still in the early stages and will lead to all kinds of new applications and business models in the future. •

The SINTAS research project was conducted by three PhD students and their supervisors. **Laura Cordova Gonzales** (with supervisor Tiedo Tinga) worked on the properties of the metal powders used and the parts produced with them. Both **Bram Westerweel** (with Rob Basten) and **Nils Knofius** (with Matthieu van der Heijden) worked on the impact of AM on downtime and spare parts stocks.

Ten key insights of SINTAS

1 AM is particularly promising when regular supply is absent or very difficult and/or time consuming. This applies, for example, in the final phase of a system's lifecycle when regular part supply is discontinued, or when spare parts are needed to maintain downtime-critical systems at remote locations, such as mission areas for defense, offshore industry, mining, or space travel.

2 Printing spare parts on demand is most interesting when downtime costs are not very high. If downtime costs are high, a major lead time reduction for 'slow movers' may still not eliminate the need for spare part inventories.

3 AM can be used to manufacture a (lower-quality) part on location, keeping the system up and running while a standard part is being supplied. AM as an emergency supply source is also a promising option: that is, AM applied only when the stock of parts is running low and conventional manufacturing would otherwise be used.

4 When selecting spare parts for AM, at many companies lower-level parts (Shop Replaceable Units or SRUs) offer more potential than parts at the exchange level (Line Replaceable Units or LRUs). This is due to the complexity of and electronic parts in the latter, which cannot yet be printed.

5 In the final phase of the lifespan of a system, it may happen that the tools (e.g. molds) required for conventional part manufacturing are no longer available. In this event, AM can be used to manufacture a disposable mold for use in conventional manufacturing. This is an alternative if direct AM is impacted by certification issues.

6 It may be worthwhile considering AM for repairing worn-out parts, even when this is only temporary while a new part is sourced through regular channels.

7 AM facilitates the manufacturing of parts in a single piece, whereas conventional manufacturing may require assembly from multiple lower-level components. This part integration may have a positive impact on the failure behavior. However, it may increase lifecycle costs if the AM part cannot be repaired by replacing a single component, but instead needs to be discarded.

8 Printing environment (e.g. moisture) and powder characteristics have a great effect on the properties of printed parts. These factors should thus be quantified and carefully controlled to ensure reproducible part quality.

9 Moving to AM may require part redesign. Retaining the original (conventional) part design may be a severe limitation.

10 For new systems, it is advisable to design parts in such a way that they are suitable for AM and to prepare a digital design immediately. •

Future research questions

Reducing LRU inventories

Under which conditions could LRU inventories be abolished, and when is a combination of LRU inventories and fast LRU resupply using AM an option? What is the impact of printing lower-level components (SRUs) to reduce the inventories of reparable exchange components (LRUs)? And if it is easier and more profitable to print SRUs rather than LRUs, is a lower part exchange level in the product structure more desirable? When does this pay off in terms of costs and downtime reduction (taking into account longer diagnosis and exchange times), and when does it not?

Boosting predictive maintenance

Can AM boost the application of predictive maintenance? If failures can currently be predicted it is usually on short notice, meaning that predictive spare part supply is not feasible given conventional manufacturing lead times. However, short AM lead times may facilitate removing spare part inventories if failures can be predicted one to two weeks ahead. The same goes for environments in which maintenance checks take significant time (one or more weeks), such as planned shutdowns in the process industry. Based on inspections early in the shutdown period, an assessment could be made to determine which parts are needed. Something similar might be feasible for aircraft (C- or D-check), for example, provided that the AM certification problem can be solved.

Investigating remote situations

Local production using AM can be attractive for remote locations. Examples include defense missions (land and sea), offshore, mining, and dredging ships.

Supply chain redesign

When should a company procure and deploy AM equipment, when should AM be outsourced, where should AM equipment be located, and how should AM parts be supplied to the installed base (emergency shipments?) And in addition: how can the efficiency of AM be optimized in relation to the throughput time required to reduce downtime? High utilization of the build chamber could mean waiting time in order to create a batch of convenient jobs, which is at odds with the need for short throughput times. This should be balanced as part of the supply chain redesign. Different supply chain designs also call for different business models and contracts for parties in the supply chain.

Sustainable supply chains

Quantitative models are needed to come up with explicit estimates of sustainability effects. Local part manufacturing using nearby raw material sources reduces transportation. AM also makes the supply chain more flexible and responsive, thereby reducing non-sustainable emergency measures (e.g. supplying emergency parts via air). On the other hand, metal printing at high temperatures requires considerable amounts of energy. All relevant factors must be included in order to draw clear conclusions on sustainability effects. •

Laura Cordova | Understanding the reliability and quality of printed parts

To compare AM to conventional manufacturing techniques from a supply chain perspective, it is important to know the reliability of printed parts: the advantages of on-demand printing may be fully canceled out if AM parts are much less reliable. Metal AM parts are typically produced from powders, for example using Laser Beam Powder Bed Fusion (LB-PBF). This technique builds up parts in layers by repeatedly depositing powder layers and melting them using one or more focused high-power-density laser beams. LB-PBF potentially produces high-quality metal parts. However, the reliability of the printed parts is largely determined by the way the powders are used and stored. Laura Cordova, Materials Engineer, studied how the properties and failure behavior of printed parts are related to the properties of the powders.

Laura Cordova: 'Powders arrive at parts manufacturers stored in sealed containers to keep them dry and clean. But producers then load them into LB-PBF machines, or store the opened containers, without knowing what happens to the powders. In addition, powder remaining in the machine after the melting process is often reused for sustainability reasons. It was unclear how these practices affect the quality of the printed parts, so this is what we investigated. In addition, the strict quality requirements in the context of certification play a very important role in the aerospace industry. This makes it very important for parts to have homogeneous and repeatable properties.'

Effect of moisture on powder and part properties | Cordova began by checking what happens to the powder when it is stored in warehouses. It often absorbs moisture, but this is strongly dependent on the type of material. This moisture absorption influences how the powder flows when layers are applied in the AM machine. As a result, moisture also affects the properties of the final metal component produced. A methodology was therefore developed, in collaboration with the NLR – Netherlands Aerospace Centre, to characterize the powder properties. 'There are standard techniques used to test powders for traditional powder metallurgy, but they are not representative for LB-PBF systems. NLR has developed a flowability tool that enabled us to accurately study the flow behavior of AM metal powders. I also studied the feasibility of preconditioning the powders using two different drying treatments to remove moisture, and examined whether the properties of the builds improve if the powder is dried before and/or during the printing process. The outcome of my research can be helpful when making supply chain decisions, for example when considering application fields with non-ideal storage and printing conditions, such as army deployments or maritime and off-shore situations.'

Reusing powder is feasible | The LB-PBF process deposits much more powder than is required for the actual part. The remaining powder can either be disposed or sieved and reused. The latter option is attractive in terms of costs, but also from a sustainability point of view: much less material is wasted. Cordova: 'I investigated the effects of reusing the powder, and found that for most materials reusing the powder several times (in combination with rejuvenation) does not lead to inferior quality of the printed parts. However, the commonly-used aluminum powder AlSi10Mg was quite susceptible to degrading powder properties due to reuse.' These insights can be used to optimize the number of times the powder is reused for specific applications in terms of costs and sustainability.

Improved Aluminum alloy for AM | Special attention was paid to the aluminum alloys that are so important for aerospace applications. Cordova: 'The Al7075 alloy is mainly used in the aerospace industry, but this alloy is difficult to process in LB-PBF. For our tests we used an alloy known as Scalmalloy, which Airbus APWorks developed especially for use in AM. We compared the various properties of this alloy with Al7075, and collaborated with the US Army Research Laboratory on their vibration fatigue behavior. For most properties, Scalmalloy outperforms the other AM aluminum alloys, and in many cases it performs also at least as well as conventional materials. Only Scalmalloy's fatigue lifetime seems to be just half the lifetime of conventional parts.' •

Some major findings and recommendations:

- Powder homogeneity is important to obtaining high reliability and repeatability of a part's properties.
- Powders that contain moisture lead to lower-quality parts, so powder usage and storage must be carefully controlled, especially in non-ideal conditions, must be carefully controlled.
- Drying the powder is only proven to improve the flowability of the powder layer during the spreading step.
- The powders tested differed in composition and morphology; Ti6Al4V and Inconel 718 proved to be the most robust in terms of flowability and powder reuse.
- Powder can be reused several times in combination with rejuvenation, depending on the powder material and final application.

Marc de Smit

NLR - Netherlands Aerospace Centre | Grip on the granule

Very recognizable from your own daily routine in the kitchen: in the first cappuccino you make, the spoon stays upright in the foam. In the next cup – with milk from a new carton but the same brand – the foam collapses immediately. These types of differences in material properties also appear in metal powders for metal AM. 'But products should always be reliable. Thanks to SINTAS, we now have more insight into what influences powders' properties,' says Marc de Smit, senior R&D engineer at NLR – Netherlands Aerospace Centre.

De Smit joined NLR eight years ago assigned with setting up a facility for metal AM. He explored NLR's customers' need for this, scanned the market for technologies, selected the equipment, and started using it. 'We had many questions about the metal powders we use. For example, what happens to the quality if you reuse powders, and what influence does moisture have? Laura Cordova from SINTAS has done very good work on that in close cooperation with our own team. Now we have a much better understanding of what exactly influences powders' properties. We were already drying the powders, but we didn't realize just how important that was. We are now better able to substantiate why we do and don't do certain things with the powders.'

Entry control of vital importance | NLR helped SINTAS in return. 'As researchers, you should not rely solely on theoretical knowledge and models,' says De Smit. 'For example, you also need to know how AM machines work in practice.' There is a vital issue involved: the entry control of metal powders. 'When a batch of powder comes in, you never know exactly what its properties are. There's a technical data sheet, but it doesn't contain all the information we need for our applications and sometimes the information is not entirely correct. The size and shape of the granules is very important and can vary.'

New tool | Up until a short time ago there was no method for testing the flow behavior of powders when applied in very thin layers in metal AM. De Smit: 'We've developed that ourselves. We're now able to apply a very thin layer of metal and then measure its density. Laura has used this tool to investigate the influence of moisture on spreadability. Others can use it too and gain experience with it. I expect it will have added value for a number of users of AM.' •

Christian Duun Norberg

Fieldmade | The next revolution in military affairs

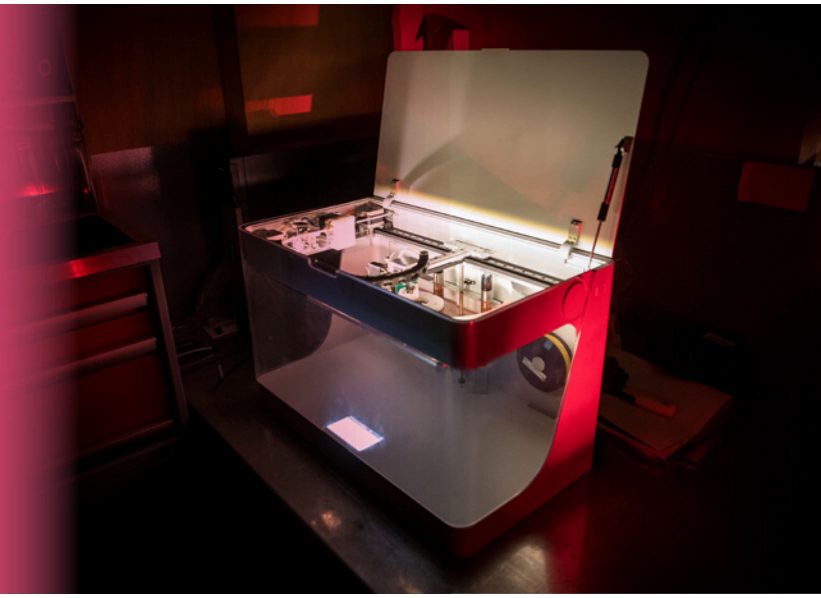
Fieldmade is a Norwegian company that develops fully-integrated deployable AM solutions for defense, maritime, emergency response, and energy sectors. Founder and CEO Christian Duun Norberg has followed SINTAS closely in the past few years. He expects no less than a revolutionary role for AM in the military domain.

Fieldmade is a spin-off of the Norwegian Defense Research Establishment (FFI), which started as an internal project. Norberg: 'I saw that technological developments from civilian R&D could to a larger extent be conceptualized to meet military needs. The armed forces were falling behind, technologically speaking. The only way to keep up is by faster development and implementation cycles. Logistics is one area that is essential for the armed forces, and at the same time often one of the most vulnerable aspects of an operation. Entire wars have been won or lost because of logistics; in addition, today's battlefields demand rapid focus shifts. AM has the potential to become the next revolution in military affairs by reducing transport needs, support modifications, bespoke equipment, and securing short response times around the globe in a cost-efficient way.'

Knowledge from the Netherlands to Norway | Norberg came in contact with SINTAS researchers in 2015 when they had just started the project. 'I had just started exploring AM myself at that time. What appealed to me in SINTAS was the combination of analytical research with practical applications. In Norway there wasn't yet any structured research like the Dutch SINTAS. For me, with a military background, it was quite interesting that the research that people like Nils Knofius have done on the selection of parts in industry has also proved to be applicable in a military context.'

Business case within reach | Norberg investigated what was needed to apply AM as a mobile system used on location, then developed a company based on it. 'We now have customers in other sectors too, such as the energy sector. What our customers have in common is that they are challenged when it comes to modeling and predicting their needs, they work in difficult locations, have to deal with obsolescence of parts, and aim for sustainability and cost-efficiency. They often need highly customized parts. When it comes to the armed forces, operability is the most important motive for deploying AM. For us at Fieldmade, the challenge is to find those niches in the market where AM is the right solution. It's all moving way too slowly in my opinion, but I remain optimistic. The business case for AM is within reach.' •

Bram Westerweel | Local printing on demand is the solution in difficult circumstances



Bram Westerweel has a background in Mechanical Engineering and completed his master's degree in Operations Management and Logistics. He defended his PhD thesis, 'Design and Control of Capital Goods Service Supply Chains with Additive Manufacturing', in May 2019. His research illustrates how AM can be successfully incorporated into capital goods service supply chains. AM sometimes appears too expensive, but it can make a difference in certain situations. Among the most promising concepts are printing at remote locations and intellectual property licensing by component manufacturers; in these cases decentralization of production can really take off.

The first study Westerweel carried out concerned the question of whether it would be interesting for an OEM (Original Equipment Manufacturer) to switch from CM to AM from the point of view of (re-)designing parts. Westerweel: 'AM offers the possibility of creating all kinds of exotic shapes, but it takes a lot of time and effort and unit printing costs can be very high. A case study we did at Fokker Services showed that AM was up to twice as expensive as CM, so you have to think carefully about when to use AM and when not to. For example, if components have to be ultralight, AM can offer a solution. The question then is who will pay the additional costs. Fokker Services has to make the investment, whereas KLM receives the benefits, for example in the form of fuel savings.'

Spectacular savings on remote missions | The second study yielded a paper with which Westerweel won an international prize. It concerned a study on spare parts for the Army in mission areas such as Mali. 'There's no DHL there to come by within 24 hours with a new part.
At best there's a convoy once every two weeks that can bring something for you.' Westerweel developed a model for onsite 3D printing. 'I assumed the army would be printing in plastic. It's less sensitive, faster, and cheaper than metal.
I also assumed that they would be printing temporary solutions; components that you only use until you have a regular component again, for example a part for a steering rod or a vehicle exhaust.' Westerweel says that the results are spectacular. 'First of all, for components for which temporary solutions can be printed on a mission, savings of up to 58% in costs can be made. Onsite inventory for these items can be reduced by 74%. Shortage costs can decrease by 92%, and the operational capacity is thus increased.'

On-demand printing of spare parts | The third study investigated aging of parts. 'What we wanted to know was how temporary components are doing in a preventive maintenance setting and whether on-demand printing can be used to fully eliminate the need to keep inventory. Normally, firms keep spare parts inventory to protect against long system downtime in the event of unexpected early failures, but on-demand printing may offer similar protection. This offers scope for industrial applications. UPS, for example, already has 3D printers at 60 locations where they can print all kinds of components on demand.' The research showed that on-demand printing can significantly reduce operating costs, especially when holding costs and direct failure costs are high. In some cases firms can use the on-demand printed parts as temporary solutions, but in other situations it can be better to use them for much longer than that.

Intellectual property issues change business models | The final study was about intellectual property. AM component design files can easily be digitally transferred from one firm to another. This allows the OEM to sell intellectual property (IP) licenses to customers, rather than physical parts. With this license and the design file, the buyers are able to print spare parts locally with much lower setup costs and much shorter lead times, creating a surplus from which the OEM can profit. It also creates an opportunity for supply chains to decentralize if buyers switch to local printing via the IP license. The research provides firms with guidance related to the types of contracts that firms can use to profit from licensing. These contracts in turn determine when buyers switch from the traditional channel with centralized production to the decentralized IP license channel. In addition, it was demonstrated that IP licensing can lead to large-scale decentralization of service supply chains, with local 3D printing facilities taking the place of centralized mass manufacturing capacity. •

Some major findings and recommendations:

- Unit printing costs can be much too high for some applications; in addition, there is an issue with redistributing the costs and benefits of redesigned components between OEM and the customer.
- AM in remote locations can have substantial benefits: less storage and a shorter downtime.
- On-demand printing can significantly reduce operating costs and can sometimes eliminate the need to keep inventory, especially when holding costs and direct failure costs are high.
- IP licensing can lead to large-scale decentralization of service supply chains, with local 3D printing facilities taking the place of centralized mass manufacturing capacity.

Jelmar den Boer

Royal Netherlands Army | Circular missions

3D printing technology increases army deployability while on missions in remote locations, while onsite part inventory can decrease substantially. 'A very surprising outcome of the SINTAS study,' according to Captain Jelmar den Boer. Den Boer is staff officer Operational Logistics and innovation coach at the Royal Netherlands Army's Logistics Knowledge Center.

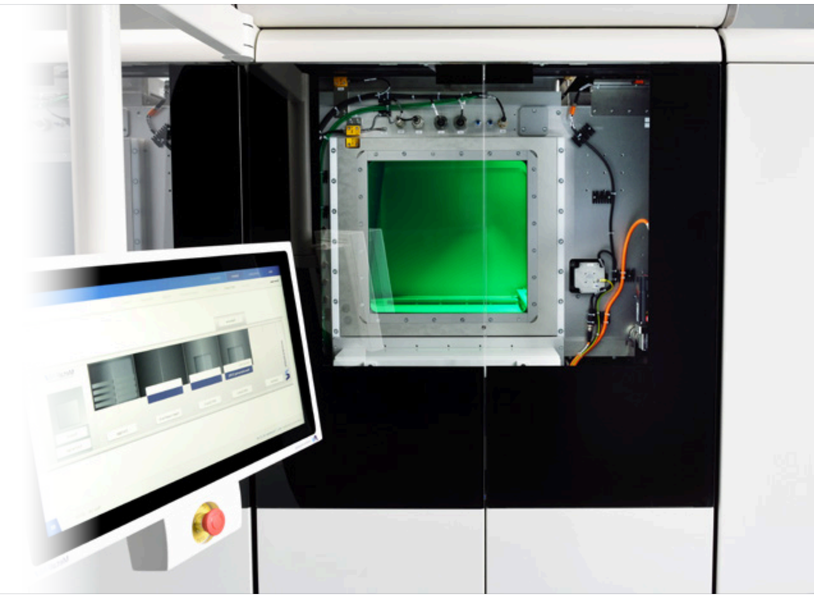
Den Boer was closely involved in Bram Westerweel's research project and believes in the potential of 3D printing. 'Even though printing a part may take 30 hours and may need post-processing, AM is still much faster than the one or two weeks it takes to order an item from the Netherlands and have it delivered to the mission location. But what does still take a lot of time is the transition to 3D printing throughout the entire supply chain. We have to select the parts that we want to print and still order from the OEM. Then drawings and contracts about that with OEMs are needed. There's also the issue of certification. We can't have printed parts breaking off vehicles and being left on public roads. If entire printers can be certified, then it will no longer be necessary to certify each individual component.'

Coffee cups in the printer | Another question is whether the army will be applying AM themselves or outsourcing it. Den Boer: 'We also need to consider where exactly to install the printers. We know that plastic printing on location is going well, but metal AM is very different because it's technically much more challenging than plastic AM. We also have to consider the quantity of stocked parts kept on location, in case a printer fails.' A new development is that the army can reuse its own plastic waste such as coffee cups and packaging as basic material for printing. 'Of course there's a limit to that, but it's nice to be able to make missions a little more sustainable and circular.'

Win-win situation | Den Boer looks back on SINTAS very positively. 'The researchers found suitable cases through the cooperation with us, and we in turn received knowledge from research for which we normally have no resources or capacity. So it really was a two-way street.' Den Boer has a special relationship with SINTAS. He became part of it thanks to his master's research in Supply Chain Management – a study he picked up after his training as an army officer. This research led to his current position. •

Daan Kersten

Additive Industries | Pick low-hanging fruit first



Additive Industries in Eindhoven is a manufacturer of metal AM systems and has grown rapidly since its establishment in 2012. With locations in Eindhoven (HQ), Bristol, Los Angeles, and Singapore, the company operates worldwide. The metal AM market is still in its infancy, but the company's job list is getting longer rather than shorter. 'The low-hanging fruit hasn't even been picked yet,' says Daan Kersten, co-founder and CEO.

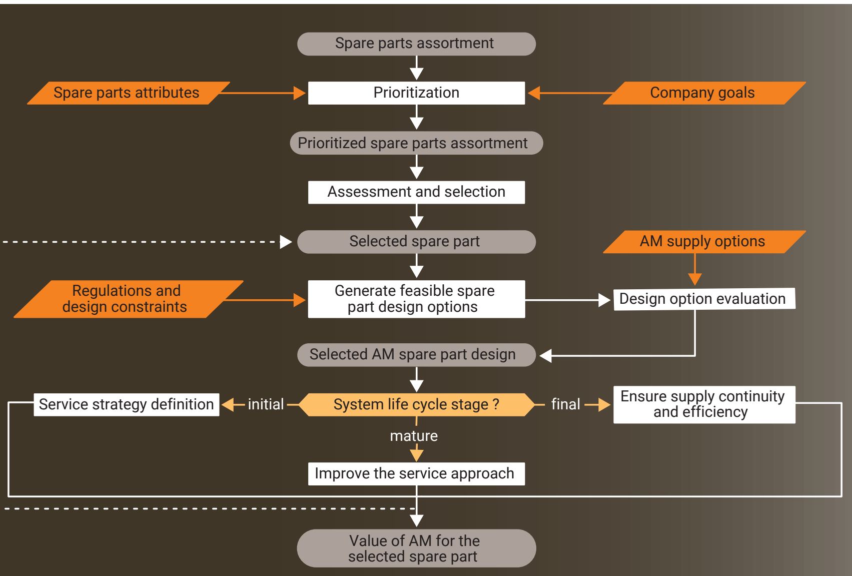
Additive Industries has participated in SINTAS from the start, offering the perspective of a metal 3D printing system OEM. Kersten recognizes many of the outcomes from SINTAS. 'AM at remote locations has huge benefits. Although the metal powder is more sensitive to moisture, it can be used if the environment is well-conditioned. Our system is modular and we could add a module that dehumidifies the metal powder first so it can cope with more aggressive environments. That increases the chances of using metal AM successfully in difficult locations.'

Labor factor decreases | The great thing about AM is that there's no need for highly-trained personnel to operate the machine onsite. 'You only need one operator. Experts can carry out the entire preparation process for the actual manufacturing from a central location, for example here in Eindhoven. AM stands for decentralized small-scale digital and fully automated production, while we keep benefiting from the economies of scale of a large company with highly trained experts. In this way, with our system design, we've been able to reduce the labor content of the total cost per 3D printed part from 20% to 2%.'

Replacement of less critical parts | SINTAS research shows that AM still encounters some economic barriers, particularly when it comes to certification. Kersten: 'In fact, redesigning certified spare parts, which were originally made with conventional technologies, for use in AM is mainly useful in situations where there is really no alternative or where the downtime of broken systems is unacceptable. I expect more of the possibility to replace the less critical parts that are currently cast or milled, for example, and for which certification is not a major problem.'

Smart data mining | 'AM is considered too much in terms of optimizing all kinds of different product properties at the same time. It must be designed smarter and produced faster and cheaper too. These ambitions make AM less feasible. Let's start with the parts where AM quickly offers added value, and progress from there. Smart software that ploughs through your database of components will certainly become very important. Imagine that 5% of it could be produced with AM – what a huge step forward that would be.' •

Nils Knofius | A roadmap for implementing AM in after-sales service supply chains



To AM or not to AM? Nils Knofius's research provides an answer. It offers decision support – a roadmap – to organisations in after-sales service supply chains to help them identify and understand the value of AM technology. The research gives quantitative insights into both when and how AM technology can be used or combined with conventional manufacturing methods to improve the efficiency of service logistics. Nils Knofius is an industrial engineer who recently obtained his PhD. He now works as a postdoc researcher at the University of Twente.

'To uncover the circumstances under which AM is useful, we first required a number of case studies. We started with the question of how to identify high-impact spare parts for the application of AM. The common practice of relying primarily on expert judgment turned out to be unsuitable given the huge number of parts to be checked – more than 400,000. We therefore developed a top-down approach that relies solely on company goals and spare parts information retrievable from Enterprise Resource Planning systems. We applied the methodology at various organizations; it turned out to work well for finding high-impact cases for AM in service logistics. It also prompted organizations, and especially their senior management, to reflect on the goals associated with using AM for their spare part operations. This stage proved to be crucial in order readjust expectations and create a high level of engagement within the organisations.'

Redesign advantages in AM may be misleading | Part consolidation – printing several parts in one piece – is a common example of a redesign. Given that consolidation has been recognized as a very promising application of AM technology for operations, Knofius explored the associated effects in further detail. 'We found that a consolidated design often leads to higher costs throughout the entire lifecycle compared to the conventional design. The key reason behind this is that replacing a consolidated AM part is often more expensive than repairing a conventional part by replacing a failed subcomponent. Overall, our results regarding consolidation are an effective example of the necessity of adopting a broader perspective when judging the effects of design changes with AM. If this isn't done, then in the long run even design improvements may lead to unforeseen costs that could render AM application debatable despite its potential functionality improvements.'

Dual sourcing can be suitable for a while | What if you have found the parts that you would like to produce with AM? Should you implement AM immediately, or use both AM and CM for a while? Knofius knows, thanks to the model he developed: 'Postponement is not a good option, although there are some exceptions. In most cases, the best choice would be an immediate investment in AM technology. However, before the company is advised to rely on AM technology completely, a transition period is often the best choice. During this transition period AM and CM methods are used in parallel. In particular, CM is then used for regular supply and AM for emergency shipments. In addition to direct cost savings, this so-called dual sourcing approach has the indirect benefit of increasing knowledge regarding the application of AM while the conventional supply source is still available.' In a case study in the aerospace industry, Knofius was confirmed in his finding that dual sourcing appears to be a suitable approach for profiting from AM more rapidly. 'Dual sourcing reduces the negative effects of high AM unit costs or low AM part quality while the benefits of a short AM replenishment lead time can be enjoyed.' •

Some major findings and recommendations:

- To identify high-impact AM use cases in after-sales service supply chains, it is advisable to apply a structured selection approach that relies on spare parts information from Enterprise Resource Planning systems and specific company goals.
- When considering AM, be aware that the potential of design improvements (such as consolidation) does not automatically equate to a positive business case. The total lifecycle costs may still increase compared to the conventional design.
- Getting ready for AM as an organization takes time; it is often advisable to have a transition period in which AM and CM are used in parallel, not only to reduce cost but also to train the organization.
- Start investing in AM sooner rather than later; training takes time and a fast transition will soon be essential to securing a competitive advantage in after-sales service supply chains.

Kaveh Alizadeh

Fokker Services | On the road to AM

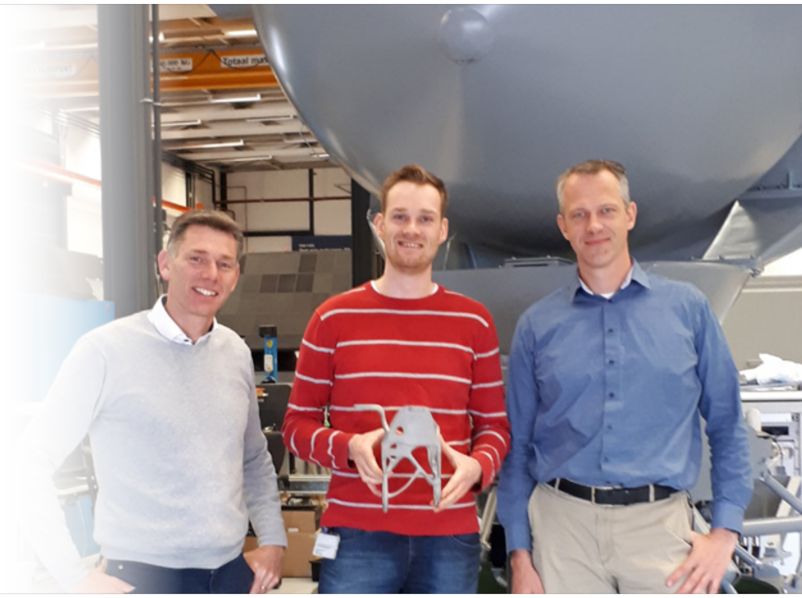
When an aircraft reaches the end of its lifecycle, it becomes more and more difficult to obtain the parts required for repairs. AM could provide a solution to this, but the SINTAS research shows that AM might turn out to be too expensive. This is mainly due to the costs that must be incurred for certification, Kaveh Alizadeh explains. Kaveh is Product Management team lead in the Material Distribution value stream of Fokker Services.

'Until some time ago AM was quite new to us. We wanted to know when and how we could use it in after-market sales. We started various technical projects related to 3D printing. Nils Knofius's SINTAS research enabled better insights into the economic aspects as well, especially with regard to our obsolescence management: dealing with the discontinuation of spare parts that we need for the somewhat older aircraft.'

Quick scan method works | Alizadeh contributed to the development of a methodology which meant that the full range of parts (more than 400,000) could be examined to identify precisely those parts that could be manufactured with AM. 'This quick scan method initially selected 6,000 items. We scored the items on all kinds of criteria relating to product characteristics. Examination of a sample of parts showed that around 20% of these could indeed be fabricated with AM. We studied a few cases to see if it would also be feasible in terms of costs. It was concluded that the certification costs were by far the highest of the costs involved. It can take up to several hundred of engineering hours to test a product and ensure that it meets all regulatory requirements.'

Change the mindset | To obtain parts that are no longer available, you can do a so-called 'last time buy,' refurbish old parts, use alternative products, and so on. Alizadeh: 'The redesign of a component is in sixth place, just before the final option: total redesign of the system. So in terms of costs, AM equals the redesign of the component: it's a very expensive option. But we did realize that tools can be made relatively more cost-effective with AM. It even gives us the option of using plastic instead of metal in some cases, hence reducing material costs. It does, however, require a change of mindset among users of these types of tools; many of them might still prefer the conventional tools.' •

Left to right: Aad van den Berg, Marnix Kuilman, Jeroen van de Wel



Thales Netherlands | Waiting for 3D-printed electronics

To Thales, the freedom of form that comes with AM is especially interesting. 'Consolidation, for instance, has some benefits. We have to store fewer small components, but logistics-wise we see few advantages in AM – that is to say: not for our spare parts at this moment.' Aad van den Berg, Marnix Kuilman and Jeroen van de Wel of Thales Netherlands nonetheless value their involvement in SINTAS.

Innovation manager Jeroen van der Wel became involved with SINTAS in a previous position at the service department of Thales Netherlands. 'We searched for candidate spare parts for which AM would have added value. It turned out there were hardly any parts suited to AM, because currently it's not possible to print electronics, or consumables such as bearings.'

The end of duct tape | Aad van den Berg, hardware architect at Thales, adds: 'We then looked at other advantages that AM might be able to offer. An MSc student who was supervised by SINTAS researcher Nils Knofius studied several cases with us. We discovered that AM could have added value for making tooling such as molds for radar covers and "one-offs". These are parts that are not supposed to break down, but sometimes do due to incidents. The delivery time on these types of parts is often extremely long and duct tape has its limitations in the long run.'

Knowledge of the process | Marnix Kuilman is a hardware designer and coordinator of AM activities. He confirms that Thales is now mainly focusing on components that can be made cheaper, faster, and less complex via AM. 'In the application of AM we benefit from Laura Cordova's research in SINTAS. After all, we need knowledge about exactly how LB-PBF works and what requirements we need to set for our suppliers in order to ensure product quality.'

Printing electronics | Van den Berg: 'The contacts we had with other companies during SINTAS meetings were also interesting. You always learn something from each other. It would have been even more interesting for us if our most important customer – the Navy – had been part of SINTAS. As far as the future of AM is concerned, we use it more often for rapid prototyping. And if 3D-printing of electronics gets easier, an entirely new world will open up for us.' •


Left: Jasper de Graaf
Right: Ben Gräve


Service Logistics Forum | Service logistics benefits from knowledge sharing

AM is a promising technology that is changing service logistics as we speak. 'SINTAS has shown the opportunities within reach. One of the major benefits of AM is making business operations more sustainable,' Ben Gräve and Jasper de Graaf of Service Logistics Forum SLF affirm. Sustainability is one of the major developments that companies, governments, and knowledge institutes handle in SLF. SINTAS and SLF cooperate in the spreading of scientific knowledge to companies. For example, in 2018 both parties organized a workshop with 70 participants. 'We are a marketplace of knowledge and expertise, and catalyst of innovations and talent,' Gräve says.

'Service logistics means much more than the timely delivery of parts for systems that require maintenance,' Ben Gräve explains. He is chairman of SLF, founded in 1993. 'I won't say that there are no more developments in that field, but the major challenge now is to properly organize the management of the entire service chain, taking care of everything that is needed to keep the systems of companies and governments operational – things like infrastructure, large production facilities, defense and medical equipment, and maritime and offshore assets. One example of this is being able to predict maintenance using big data and machine learning. This is still a relatively unexplored area for many companies, while other companies or sectors are already working with control towers – information centers where data from different sources come together. These control towers make it possible to monitor assets' operational status and the implementation of corrective – and preventative – maintenance.'

Cross-sectoral learning | Jasper de Graaf is project manager at SLF and Service Logistics program manager at TKI Dinalog. 'Service chain management means the effective control of maintenance, spare parts, tools – within all different parts of the organization, and even with partners outside the organization. This means that a challenge faced by service logistics is the integration of all these different aspects, and the cooperation between these organizational departments and partners elsewhere in the service chain.'
In addition to cooperation between supply chain partners, SLF stimulates knowledge exchange between sectors.
De Graaf: 'The larger and more diverse our network, the greater the added value for all different affiliated partners. In cross-sectoral learning from each other, competition considerations play no role. After all, you're not immediately in each other's way.' Getting new parties involved is crucial. 'For example, through a partner like Rijkswaterstaat – with whom we're currently holding round table sessions – we come into contact with the construction sector and the large engineering companies. It would be an enormous enrichment for both existing and new partners if these new partners were to stay on board, and share their knowledge and knowledge questions with us too,' says De Graaf.

Young talent | The recent developments in the F-35 program shows that sharing knowledge really has an impact on the Dutch economy. Gräve: 'The Netherlands has managed to win the contract to handle all spare parts for the whole of Europe from Woensdrecht. That assignment wouldn't have ended up here if we had not had such a good position in knowledge and expertise in the field of service logistics. The service logistics community – with industrial experience and scientific knowledge – has literally contributed to this assignment coming to the Netherlands.' In addition, SLF plays a role in the interconnection of universities and colleges, raising the level of academic education in service logistics and getting students interested in this domain.
The latter is done through Young SLF and dedicated Young Talent program components at the annual Service Logistics Summit, amongst other things.

Towards a circular economy | One emerging opportunity for service logistics is the development towards 'product as a service' – in other words, from ownership to usage. Gräve: 'Look for instance at the rise of shared cars and 'mobility as a service'. You no longer need to buy lamps for office buildings; you conclude a contract with a supplier who ensures that you'll always have light. This is also happening more and more in industrial sectors: you buy the uptime of certain assets, as it were. This development requires a new vision of the service offering of OEMs and completely different business models arise for this.'
The challenge of extending assets' lifespans is in keeping with the circular concept; after all, it's about the optimum use of materials. So the sector of service logistics has a track record for the circular economy, Gräve says. 'Return logistics once started with the collection of broken, used or written-off products and packaging. Now all this goes to the next level. We already know of good examples of companies >

that are now making optimal reuse of their used products, sometimes in the form of refurbishment and sometimes through the recovery of parts or valuable materials. It's a new development that also raises new knowledge questions. As SLF, we support the formulation of new research projects and the composition of consortia.' In addition, SLF organizes thematic sessions with, for example, excursions to company sites. 'It means you can take a peek behind the scenes and see what your neighbor's doing, and that often proves very inspiring,' says Gräve.

The energy transition as an opportunity | De Graaf: 'The development towards sustainability in our society continues. And even better: service logistics can make a hugely important contribution to this.' Gräve: 'Think of sun and wind energy: how do you keep those systems for both the generation and distribution of energy up and running for as long as possible – and on sea too? Service logistics will also play a vital role if all households in the Netherlands that use natural gas make the switch to other technologies.' De Graaf: 'In addition, service logistics is an agent in energy transition. Consider, for example, the zero-emission transport used in urban areas. There are specific projects using city bikes for service engineers and spare parts distribution. So we're part of the energy transition ourselves and are actually working on it already.' •

Colophon

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Manon de Koning: portrait Jasper de Graaf p. 20
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Rijksoverheid

NWO

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