BUSINESS
FINLAND

ADDITIVE MANUFACTURING WORKSHOP RELATED TO HX PROGRAM

SUMMARY

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“FINLAND NEEDS A HIGH LEVEL ADDITIVE MANUFACTURING (AM) PRODUCTION CAPACITY”
- Statement agreed by the workshop participants

“CURRENT METAL AM CAPACITY IN FINLAND IS NOT SUFFICIENT FOR TIMES OF CRISIS”
- Statement agreed by the workshop participants

“ADDITIVE MANUFACTURING COOPERATION RECEIVED FROM OEM WITHIN HX PROGRAM WOULD HELP MY ORGANIZATION IN A SIGNIFICANT WAY”
- Statement agreed by the workshop participants

”IF WE CAN GAIN AM COMPETENCE ADVANTAGE COMPARED TO OUR FOREIGN COMPETITORS, ADDED VALUE WOULD BE COUNTED IN MILLIONS”
- Workshop participant from a large Finnish company

“IF FINLAND DOESN’T HAVE HIGH-QUALITY RESEARCH IN AM IT MAY END ALL TOGETHER”
- Workshop participant from research sector

VERSION MANAGEMENT

Version	Checked	Approved	Date	Change history
1.0	THä	MLe	22.04.2020	Document created

Appendicies

	Item	Number of pages
1	Poll results	
2	Groupwork 1 raw data	
3	Groupwork 2 raw data	

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SYMBOLS AND ABBREVIATIONS

3DP	3D printing
AM	Additive manufacturing
AMCE	Additive manufacturing center of excellence
CT	Computer tomography
DT	Destructive testing
FDF	Finnish defense forces
IP	Industrial participation
LPBF	Laser powder bed fusion
NDT	Non-destructive testing
OEM	Original equipment manufacturer

1 INTRODUCTION

1.1 HX-program

Finland will replace its Hornet fighter jets by 2030, and the bidding process for the program is now ongoing. The procurement includes an obligation for industrial participation: the winning bidder and its partners will cooperate with Finnish companies, with the value of the participation being 30 percent of the purchase price (Business Finland, 2019).

The primary objective of industrial participation is to ensure the military security of supply of defense industry products from Finnish and foreign manufacturers and the availability of critical technology in any circumstances. The secondary objective is to ensure the development of Finnish technology and competence in the future.

Industrial participation (IP), involves an evaluation of how cooperation between HX tenderers and domestic industry would be realized. The total value of the industrial participation is approximately EUR 2-3 billion.

Additive manufacturing (AM) has passed the peak of the hype curve, and is steadily becoming an established manufacturing method. It is deemed critical that qualification of components aimed at serial production is ramped up in order to not miss opportunities that will otherwise be ordered from abroad, for example from Sweden or Germany.

Finnish defense forces have listed additive manufacturing as one of the interest areas in industrial cooperation. (Indirect IP).

HX-program is a unique opportunity to create industrial-scale additive manufacturing expertise in Finland, which serves and develops Finnish defense and security industry expertise, and also brings technical expertise available for other industries.

This report will list the needs collected from different organizations and companies during the workshop. It will also support discussions and decision making of HX tenderers.

1.2 Workshop participants

The workshop was carried out via online live meetings on 2nd and 3rd of April 2020 due to the COVID-19 situation. The workshop had participants from:

- Finnish Defense Forces
- Government
- Business Finland
- Companies
- Research institutions
- Academia.

1.3 Workshop target

In the workshop the participants considered how the know-how gained through the HX-program, or industrial cooperation could affect the competitiveness of participants' companies and Finland. The HX-program presents an opportunity to create industrial-scale additive manufacturing expertise in Finland, which serves and develops Finnish defense and security industry expertise. It also brings technical expertise to other industries, but to have cooperation with the OEM requires a profitable business case to work in.

The aim of the workshop was to find a national state of mind, as well as identify a healthy additive manufacturing business case based on the needs of the Finnish defense forces, companies and research.

This report has been created with what said earlier in mind, and it will identify on a high level what should be done to achieve this goal, and what we can achieve through industrial cooperation in the HX-program.

Following topics were worked on with workshop participants to get this information

- List of your needs & wishes from shareholders related to additive manufacturing
- What we would like to get from HX program OEM's in a terms of a) know-how b) production
- Identify consequences to each shareholder?
- What kind of business cases HX-project could enable related to AM?

In the workshop, two polls were executed and the results can be found from the appendices of this document.

1.4 Operating environment in Finland

Current state: How it looks in Finland

- AM rarely specified in technology roadmaps
- No dedicated funding for AM
- Technology not seen as a business enabler
- Unseen risks and conservatism
- Need for a business case to justify the funding

Organizations need to understand the potential of AM better and ideally be able to answer the following questions

- What would need to change in my design-buy-make-move-fulfill supply chain to help stay ahead of the game?
- What is the business case and what does it look like?

- What is our “Future of Manufacturing?”
- Which applications will play an important role in the future?
- How will customer demand develop and where can we add the most value in the future with additive manufacturing?
- What is the customer need?
- What would the roadmap look like to develop our capabilities?

2 BUSINESS CASE

The rapidly evolving capabilities of AM create a challenging field for companies to determine which parts can be feasibly produced. Rather than focusing on the technical details, the first step for decision makers is to understand the practical applications of AM in their business to address the following questions (https://medium.com/am-on-the-cusp/making-the-business-case-for-additive-manufacturing-a-manager-s-guide-2ce592096d97)

- Is demand for the item hard to forecast and frequently fluctuating?
- Do you struggle with long production lead times for tooling, casting, forgings machining's etc.?
- Does the manufacturing process for an item have high scrap rates or require significant amounts of labor for assembly or post processing?
- Has the price of an item increased by a factor of 2x or more over its lifetime?
- Do you store, inventory and manage items for extended periods of time prior to end-use, increasing cost and tying up your company working capital?
- Have you been forced to discontinue “no-bid” or outsource the production of an item as a result of reduced demand driving down the production volume?
- Would your value proposition be stronger with customized items to meet each of your clients’ needs?
- Is an item complex and challenging to produce or do you sacrifice the functionality due to inability to produce the desired shape by using traditional manufacturing?
- Do you produce items in low volumes making it more challenging to reduce the per unit tooling or other costs?

At the moment many companies struggle with the business case creations for additive manufacturing. In business case creation companies can search for the following matters:

- Cost reduction
- Performance improvement
- Supply chain disruption
- New market & growth opportunities

Business case analysis helps to realize the total value of additive manufacturing when it calculates the monetary benefits of better product performance and functionality, product usage, customer service and marketing.

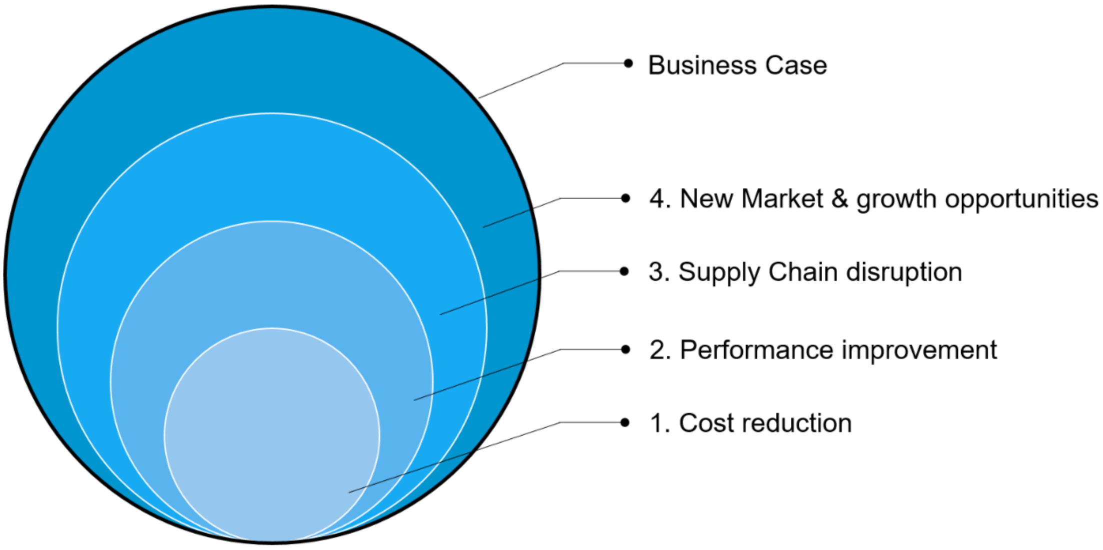
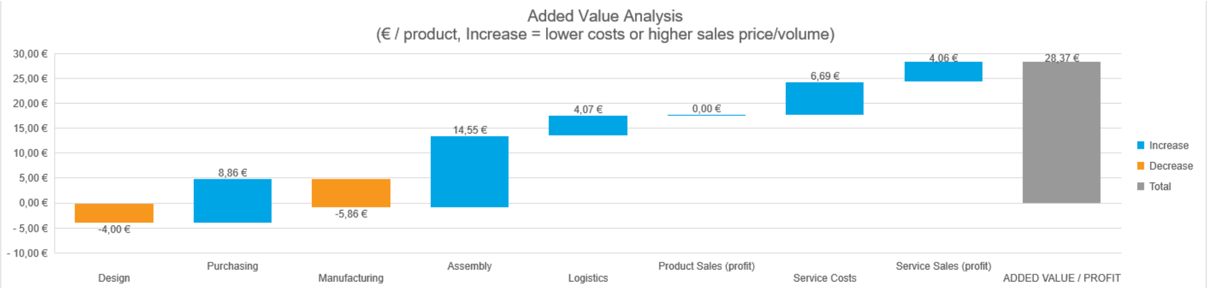


Figure 1 How your business case looks like.

From the perspective of a company with its own product, business case creation is quite straight forward. The only effort needed is to calculate the added value of new design compared to old design. However, to make justified decisions it is important to analyze the value effect in detail and in every step in the supply chain, not just looking at the manufacturing costs.

Value analysis contains all of the cost effects from design, purchasing, manufacturing, assembly, logistics and service but also the effects for product and service sales. Value analysis can be done in many different ways. Below is an example of Etteplan's value analysis tool for business case creation.



	Design	Purchasing	Manufacturing	Assembly	Logistics	Product Sales (profit)	Service Costs	Service Sales (profit)	ADDED VALUE / PROFIT	
New Design	-4,00 €	8,86 €	-5,86 €	14,55 €	4,07 €	0,00 €	6,69 €	4,06 €	**28,37 €**	€ / product
	-20 000 €	44 309 €	-29 289 €	72 746 €	20 353 €	0 €	33 426 €	20 308 €	**141 853 €**	€ / total volume
									28 371 €	€ / year
	Fixed price project costs	Ordering costs	Manufacturing labor costs	Part collection costs	Packing and sending costs	Product performance & functionality	Spare parts inventory carrying costs	Customer service		
		Inventory carrying costs	Manufacturing tooling costs	Assembly work costs	Inventory carrying costs	Product usage	Maintenance work costs			
		Transportation costs	Material costs	Assembly tooling costs	Transportation costs	Customer service	Maintenance tooling costs			
		Purchased parts costs	Machine costs	Quality inspection & rework costs		Marketing	Reclamation costs			
			Waste costs							

Figure 2 Example of Etteplan's Added Value Analysis tool output sheet's information.

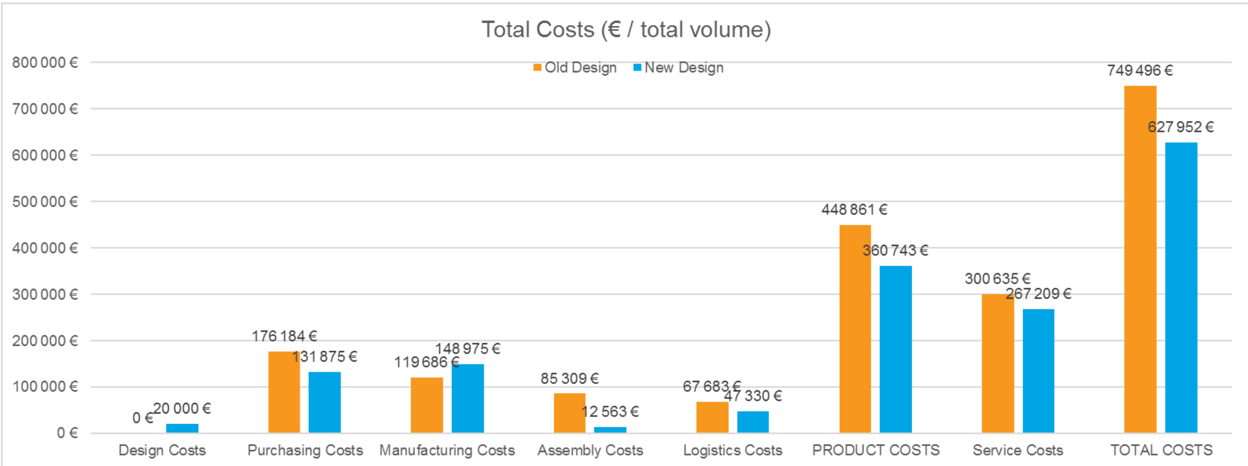


Figure 3 Example of Etteplan's Added Value Analysis tool output sheet's information.

3 GROUPWORKS

In both of the workshop groupworks, participants were divided into 4 different teams. The same assignment and time were given to all of the teams. After a groupwork, the results were summarized and shared with participants at the end of the day.

In the following sections the targets and results summaries for both groupworks are presented.

3.1 Groupwork 1 - HX Scenarios

Before the first groupwork Finnish Defense Forces (FDF) explained their point of view and requirements for the HX program so that each participant had the same background knowledge.

The requirements for AM related IP were

- Military core and HX-project as a spearhead
- Know-how for FDF and strategic partners
- Qualification capabilities for aerospace needs to be acquired
- Knowledge needs to eventually be transferred from aviation to other FDF branches
- All co-operation with OEM needs to be according to EU legislation

3.1.1 Target

Assignment for the first groupwork was defined as

Create a list of your needs & wishes related to additive manufacturing + prioritize them

A set of guiding questions were provided to help come up with needs related to additive manufacturing:

- What is needed to start utilizing AM?
- What is needed to achieve your AM related goals?
- What is needed to take the next leap?
- What is required in order to accept AM as a standard manufacturing technology?

Each of the participants were instructed to come up with their own thoughts related mainly to their own field (industry, Finnish Defense Forces, research & academia) before collecting them into a one complete list.

After creating an initial list of needs and wishes, the group was asked to divide them into two different scenarios

- Only know-how is transferred from OEM
- Both know-how and production is transferred from OEM

Due to a tight schedule and active discussions for some groups the division between know-how and know-how & production transfer was done by Etteplan's additive manufacturing specialists.

A collective list of ideas is in the appendices of this document. An overview of the list can also be seen in Figure 4.

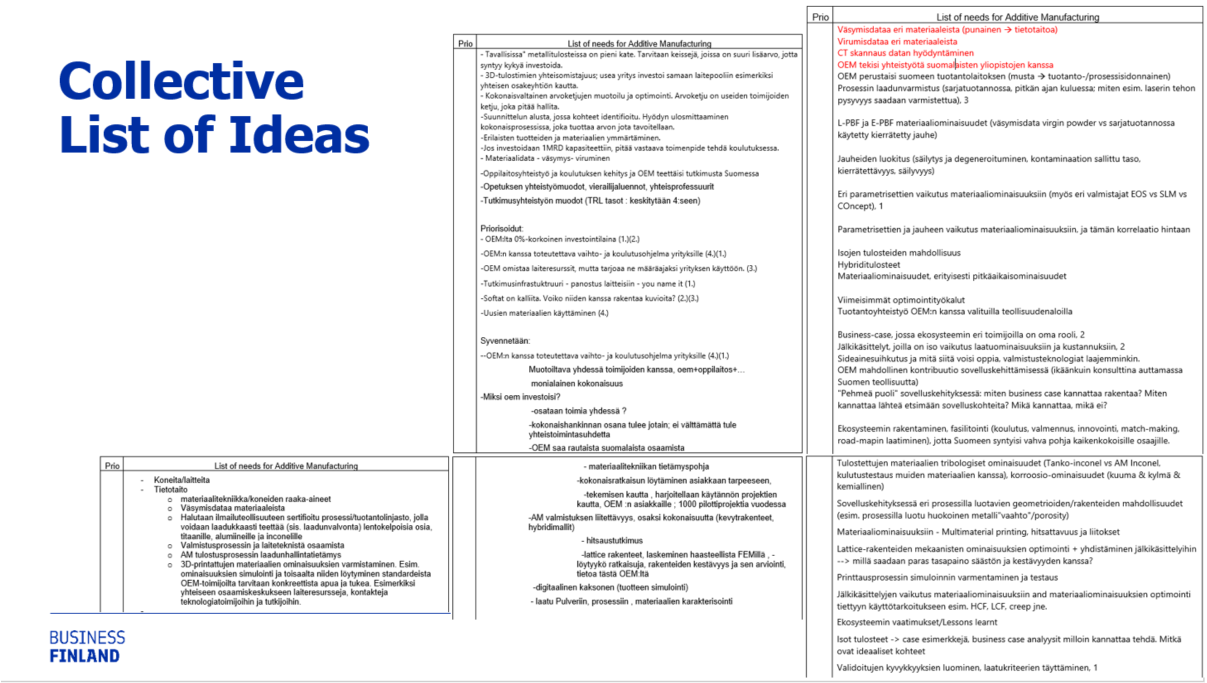


Figure 4 List of needs and wishes created by four teams throughout the day.

3.1.2 Summary HX scenarios

As it can be seen from the overview, a quite impressive list of needs was created by the participants. As many of the needs and wishes were relatively close to each other, a step was taken to create a summarized list for sake the of better manageability.

Some of the needs and wishes listed were out of scope for the HX program and therefore have been filtered out from the following steps.

The summary can be seen in Table 1. It is to be noted that things listed under "Know-how transferred" are included in "Know-how & production transferred" automatically, even if not separately listed again, as can be seen in Figure 5.

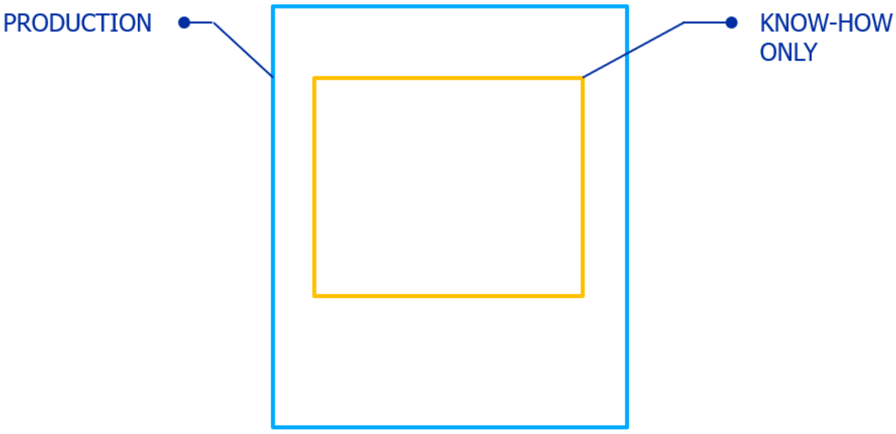


Figure 5 Relation between "Know-how transferred" and "Know-how & production transferred".

Table 1 Summary of listed needs and wishes.

Know-how transferred	**Know-how & production transferred (including also the list from the left)**
- Component qualification	- Certified AM production for aerospace
- Quality assurance for serial production	○ Titanium, Inconel, aluminum, etc.
- Material information	- Machine investments
○ Fatigue, creep, static properties etc.	- Operating procedures for production facility
- Printing process information	- Process quality know-how
○ Process optimization (productivity, performance, etc.)	○ Repeatability & reliability
○ Parameter sets	- Machine, material & parameter understanding
- Post-processing know-how	
- Quality control know-how	
○ NDT & DT know-how e.g. CT scanning	
- Design know-how	
- Powder knowledge	
○ Powder qualification (virgin, recycling, etc..)	
- Education	

Looking at the list above it appears that if the OEM would transfer only know-how, there would be a reasonable amount of knowledge transferred. For example, regarding material information like fatigue, the knowledge required in quality levels 1-3 (referring to “Levels of AM Quality”, see *Figure 12*) could be obtained. One could imagine that with know-how transfer alone AM capabilities in Finland would improve, more business opportunities would be created and it would provide a shortcut to the front line of AM adaptors. But before jumping into conclusions, let’s have a closer look.

Already from the wording it can be seen that quality is one of the key needs that participants of the workshop have listed: many of the listings in the table above mention “quality” or “certified”. But what does “quality” mean when talking about additive manufacturing?

In Figure 6 an outline of the things affecting quality in AM has been visually presented. It can be seen that quality is affected a bit by everything. Some of the things are of course more manageable and have a smaller affect while others can have a more drastic impact. At the top level, things that have an affect are grouped to:

- Manpower
- Milieu
- Machine
- Material
- Method

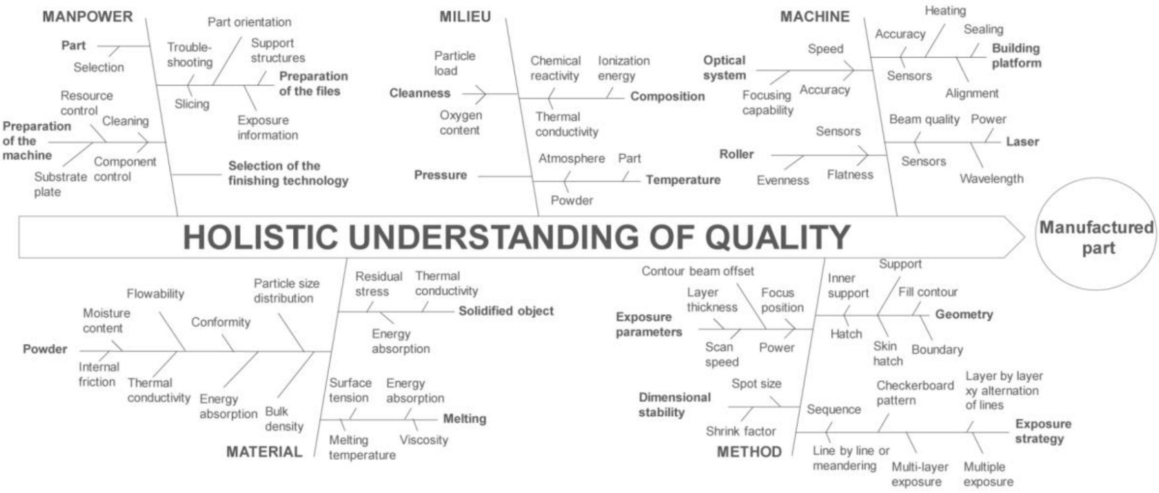


Figure 6 A Simplification of what affects quality in AM, (Fit Ag, 2020).

When talking about metal AM, which in general is more demanding than 3D printing plastic components, each of the components is produced by melting layer-by-layer the cross section of the component. In the most used metal AM technique, laser powder bed fusion (LPBF), a laser is being used to melt the metal powder. This means that when melting the component, material properties are actually defined during the melting process. This makes metal AM considerably different than subtractive manufacturing of components. It could be said that each machine is sort of a "mini steel factory".

When looking at this matter from the perspective of quality, there can be a large variation in material properties between the components produced in different machines. This is especially true between different machine manufacturers. Some differences can also be found within same make and model, but they usually tend to perform under a skillful operator within a certain window of deviation that the machine manufacturer has specified.

So when talking about quality, there are quite many things that need to be taken into account. In Figure 7 the text in blue shows the needs and wishes that are directly mentioning quality or certification. Needs and wishes marked in orange color do not mention quality in the name but are vital in the quality control process of AM part production.

Thinking about the material information and fatigue again, to gain a reliable access to quality level 4-5 information, a production transfer would be needed to keep up to date with the information and to make sure the information is for the machines that are being used for production. As one of the representatives from research sector put it:

"Level 5 can be achieved only if also production is transferred, not only know-how. The reason is that it is not just about the machine but about the whole production process which needs to be frozen"

The final comment on the results of groupwork 1 can be summarized that the participants are very much interested in transferring the knowledge of all things related to quality in AM to Finland. This seems to complement the trend that Finland is lacking many skill areas to produce highest level of quality components, as it was discovered in the report "Additive Manufacturing Center of Excellence in Finland" (a link to the report can be found in section 4 of this document).

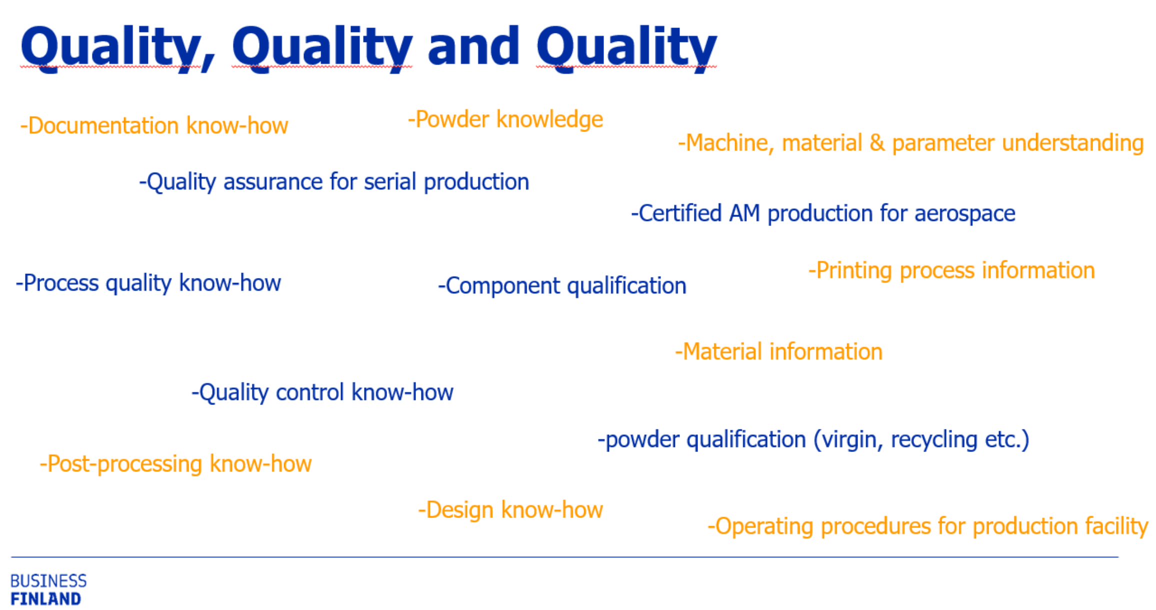


Figure 7 Quality related needs and wishes created in the groupwork 1.

3.2 Groupwork 2 – Consequences

After the first groupwork day, participants were able to rest over the night to recharge for the second day.

3.2.1 Target

The target for this groupwork was to identify the consequences that additive manufacturing can bring to each of the shareholders within HX program context. The shareholders were divided to:

- Finnish Defense Forces
- Finnish companies
- Research & academia
- Hospitals

In addition to consequences, the target was also to ideate what kind of business cases HX program could enable related to AM.

Similar to groupwork 1, participants were instructed to think for the two scenarios where the OEM transfers

- Know-how
- Know-how and would purchase machine capacity

A list of guiding questions were provided to participants to help boost the ideation

- What areas in my supply chain and operations are potentially affected by 3DP?
- How do I protect my business and take advantage of the opportunities in the scenarios?
    - Know how is transformed
    - Both production & knowhow is transformed
- What would need to change in my design-buy-make-move-fulfill supply chain to help stay ahead of the game?
- What is the business case and how it would look like?
- What is our “Future of Manufacturing?”
- Which applications will play an important role in the future?
- How will customer demand develop and where can we add the most value in the future with 3D-printing?
- How can we incorporate this in to new services business models and services solution propositions?
- Which other disciplines should be involved and what should they bring?
- How should we execute this development?

3.2.2 Summary – consequences

The groupwork produced a large number of different consequences for different shareholders and for the sake of clarity they are gone through shareholder by shareholder.

3.2.2.1 Finnish Defense Forces

In Figure 8 an overview of all the ideas created can be seen. They are also in the appendices for a closer look if wanted.

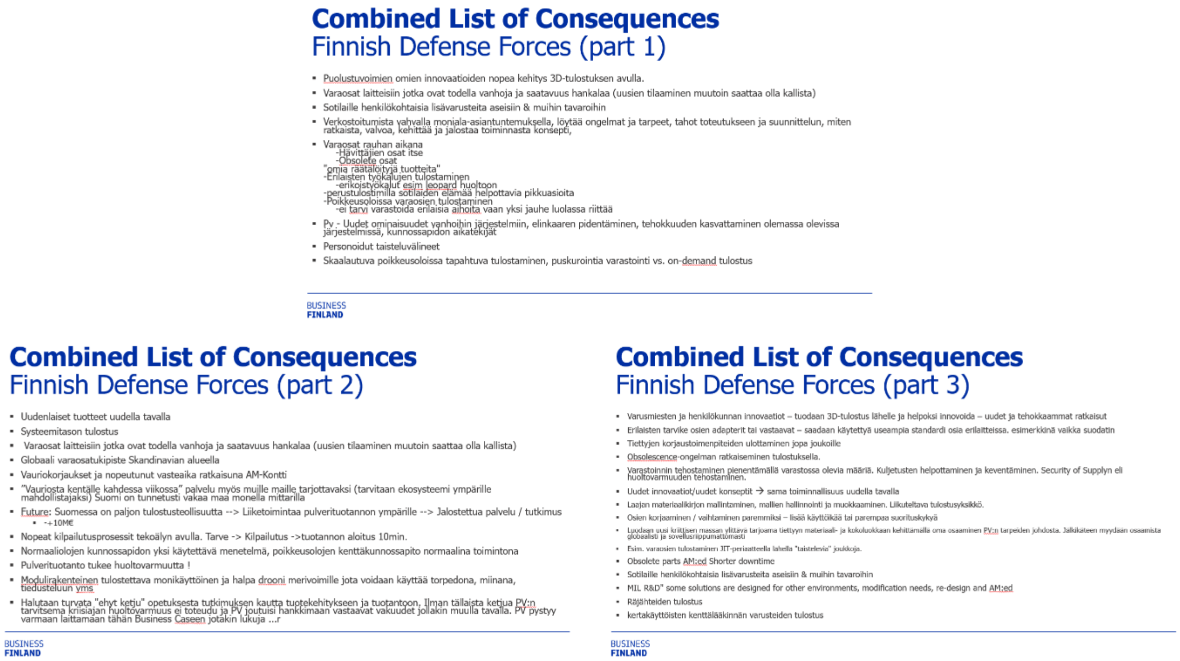


Figure 8 Overview of all the created consequences for Finnish Defense Forces.

As the idea list is quite vast and contains similar ideas, they were collected into a more readable form in Table 2. The listing has also been divided into two sections to clarify the difference between know-how transfer only and know-how & production transfer. It is to be noted that things listed under "Know-how transferred" are included in "Know-how & production transferred" automatically, even if not separately listed again.

Table 2 List of consequences for Finnish Defense Forces.

Know-how transferred	**Know-how & production transferred (including also the list from the left)**
Components belonging to quality levels 1-3 can be catered	*Flying components can be catered (quality levels 4-5)*

- Spare parts during normal times and times of crisis
  ○ Land
  ○ Sea
- Producing spare parts close to troops
- Short downtime
- Increasing lifetime of equipment
  - Reducing the need for "cannibalizing" old equipment
	- Spare parts during normal times and times of crisis
	- Increasing lifetime of equipment
	  ○ E.g. Hawk training fighters
	- Possibility to offer additive manufacturing production to partner countries (Scandinavia)

- Rapid development of own innovations in Finnish Defense Forces with the help of 3D printing ○ Improvements for equipment ○ Accessories for soldiers ○ Tools for maintenance	

As can be interpreted from the table above, airworthy components are possible to produce only when both AM know-how and production is transferred from the OEM to Finland. There seems to be many good business cases within the Finnish Defense Forces in less critical applications as well, as was described by one of the representatives of the military:

“Replacement of non-critical part in tank had a long lead time (1 year) and high costs. With AM, downtime would have been few days or weeks and cost approximately 1% compared to traditional.”

3.2.2.2 Finnish Companies

Figure 9 shows the overview of the ideas of possible consequences for Finnish companies. The comprehensive list can be found in the appendices.

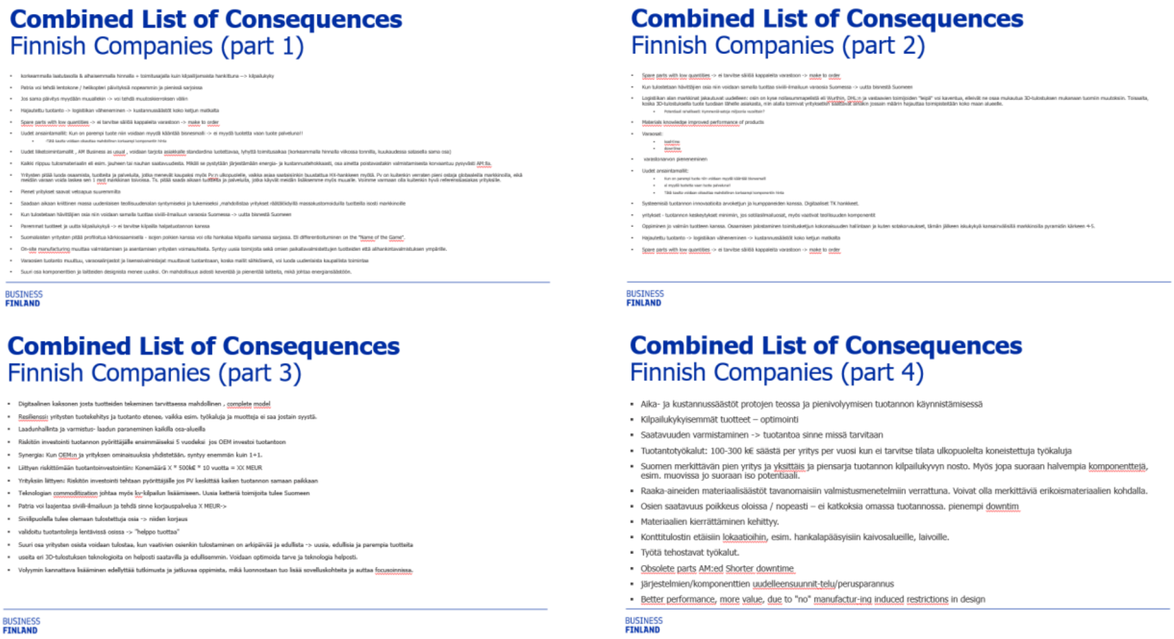


Figure 9 Overview of generated ideas for Finnish companies.

Many of the raw ideas for consequences are similar to each other between different teams so they have been combined and can be seen in Table 3. Some of the ideas were unfortunately out of scope for HX program so they have been excluded from the table. To clarify the difference between know-how transfer only and know-how and production transfer, the list has been divided into these two sections.

Table 3 List of consequences for Finnish companies.

Know-how transferred	**Know-how & production transferred (including also the list from the left)**

- New business models, e.g. product as a service
- Design capabilities required
	- New companies could be established, e.g.
	    ○ AM production facility
	    ○ Powder production facility
	- New business opportunities by invading new business areas e.g. from military to civilian

Quality level 1-3 catered
- Spare parts
    ○ Shorter lead time
    ○ Less warehousing
    ○ Better parts
- Better products → competitive advantage by differentiating from competitors
	Quality levels 4-5 catered
	- Spare parts
	    ○ Shorter lead time
	    ○ Less warehousing
	    ○ Better parts
	- Better products → competitive advantage by differentiating from competitors

The sorted list reveals us that participants see new business potentials, should additive manufacturing support be received from OEM in the form of know-how or know-how and production transfer. Particularly it would enable new business models and for example spare part production could be utilized in both critical and less critical components. New design skills are needed to create components giving extra value and competitive advantage over rivals. When being able to utilize the advantages of AM, new companies could be established to grow the AM field in Finland. As a whole, having additive manufacturing know-how and production both transferred to Finland would open up possibilities for existing and new companies that have not been reachable so far, or at least the process would speed up significantly.

Statements that the participants from industry expressed, regarding AM becoming more commonly used, are encouraging:

”Size of AM spare part business will be X-XX MEUR in five years”

"If we can gain AM competence advantage compared to our foreign competitors, added value would be counted in millions"

"100 new design engineers would lead to 15 MEUR added revenue"

3.2.2.3 Research and academia

In Figure 10 an overview of all the ideated consequences can be seen. They are also attached in the appendices.

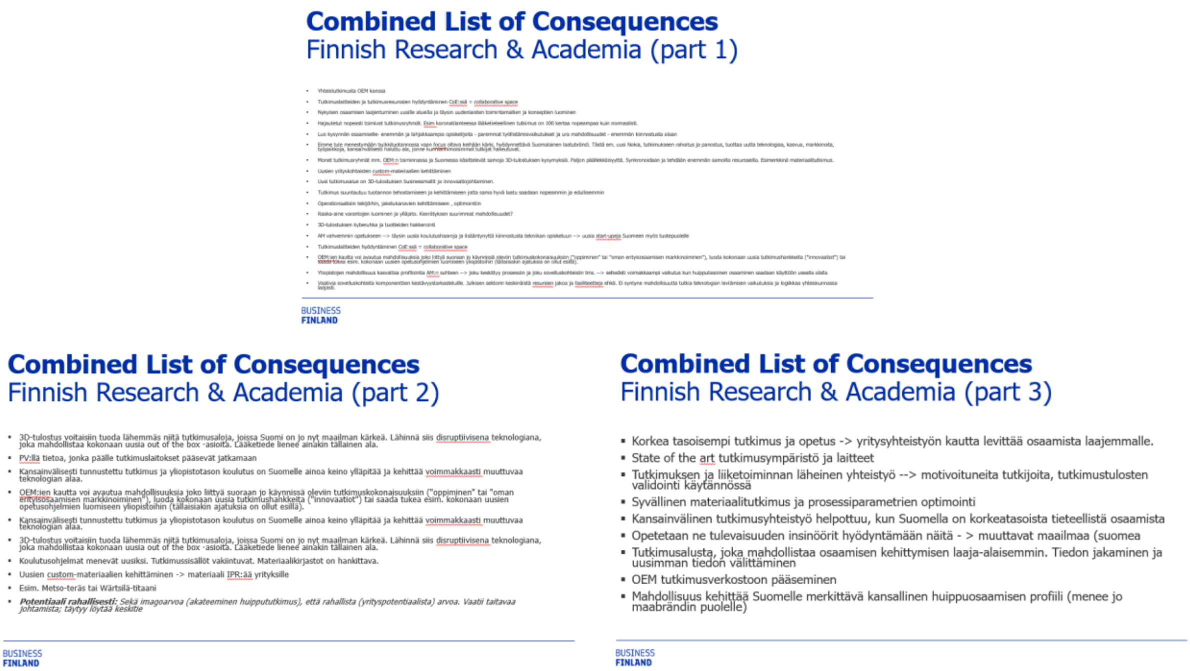


Figure 10 Overview of generated ideas for Finnish research and academia.

As was with previous cases, also research and academia got plenty of ideas to answer the questions: What could be done in terms of wider additive manufacturing adaptation and what would be the consequences to that field? Many of the ideas were unfortunately a bit out of scope for the HX program so they have been excluded from the list shown in

Table 4. Also, similar ideas have been combined into one.

Table 4 List of consequences for Finnish research and academia.

Know-how transferred	Know-how & production transferred (including also the list from the left)

- Cooperative research with OEM / OEM's network
- Improving operational factors, distribution channels etc.
- Design tools
- Testing and quality aspects
- Tools to prevent cyber threat for AM (digital files) and hacking the products
- International research cooperation eases up if Finland has high level scientific knowledge
	- State of the art research environment and equipment (in universities or center of excellence)
	- After AM becoming accepted manufacturing method, future research may focus to
	  ○ Improving productivity
	  ○ Creating customer specific custom materials

The level of research in Finnish research and academia at the moment is in a good level but cooperation with an OEM could take that even further. If know-how would be transferred, cooperation with the OEM or OEM's network would be especially beneficial to Finnish research and academia, potentially enabling easier cooperation in international research projects. Research could also widen to cover also operational factors and distribution channels. Tools and information could be received from OEM to study for example cyber threats for AM.

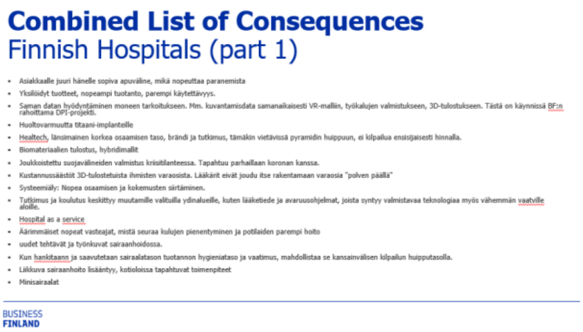
If both know-how and production are transferred, it is highly likely that Finnish research and academia would be provided access to a state of the art research environment and equipment, ensuring high quality research. Later on, once AM is accepted by default to be one of the key manufacturing methods and is trusted, research could focus on improving productivity or even creating custom materials for companies, thereby ensuring competitive advantage.

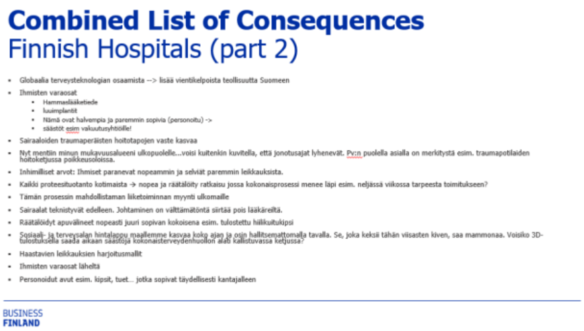
One thing became evident though and one of the participants from the Finnish academia said it well:

"If Finland doesn't have high-quality research in AM it may end all together."

3.2.2.4 Finnish hospitals

Creativity of participants was present also in the last one of the four shareholder groups: Finnish hospitals. An overview of all the listed ideas for consequences can be seen in Figure 11. The list of consequences can be seen more in detail in the appendices.





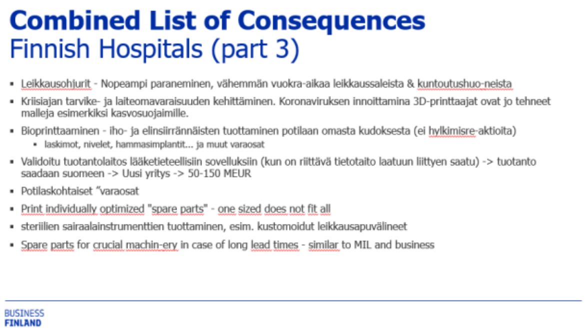


Figure 11 Overview of generated ideas for Finnish hospitals.

Participants created once again a great list of ideas on what could be the consequences for Finnish hospitals should we obtain either know-how or know-how and production from the OEM in HX program regarding AM. Like in previous cases, it was also true for this one, that some of the ideas were spot on for the HX program in mind while others were great for the Finnish hospitals in general but not in the scope of HX program. In Table 5 is gathered a collective list of the consequences that could happen in AM know-how and know-how & production transfer regarding the HX context.

Table 5 List of consequences for Finnish hospitals.

Know-how transferred	**Know-how & production transferred (including also the list from the left)**

- Certification process for production facility
- Material qualities
- Quality process
    ○ Could provide basis for medical printing facility
        ▪ Creates business opportunity for a new / existing facility operator
	Certified medical printing facility
	- Custom "spare parts" for humans
	    ○ Quicker to use than stock components
	    ○ Cost savings (reducing manual labor)
	- Tools needed in surgery
	    ○ Faster to operate and better fit
	        ▪ Quicker recovery

	▪ shorter use time of hospital rooms -> savings - Could serve local and global markets - Spare parts for equipment

Having once again the assumption that the OEM has, or has access to, a qualified AM production system for airworthy critical components, Finland could receive as a know-how transfer the needed information on how to setup a certified process for a production facility and how to manage quality assurance. This in turn could help either an existing facility operator, or a new operator, to create a business around providing certified medical components. Knowing materials and their quality is a key factor in this business. Less critical components could also be produced, such as custom made casts or supports for example.

It has been assumed that both critical airworthy components and medical components need to undergo a heavy certification process and quality control in production, and therefore the knowledge on airworthy components could be applied to great extent to medical components as well. At a minimum the learning curve would be shorter.

Should Finland receive both know-how and production transfer from OEM, a certified medical printing facility should be rather straightforward to set up. This in turn could provide “spare parts” for humans or tools needed in surgical operations that are produced locally. At the moment they need to be ordered from Europe. Using custom made implants and tools in surgical operations result to shorter operating times, better recovery times and overall cost savings.

A certified production line would also make it possible to produce spare parts for medical equipment as well. Innovators from the Finnish hospitals could share their ideas in the facility (or AM center of excellence) creating more products and ways of working to be offered for the market. This kind of a production facility does not need to serve only local Finnish customers but service can also be offered globally.

Efforts and advances on the medical side also help military medical care during normal times and in times of crisis.

Simply put, having medical AM expertise brings benefits for all parties:

“Customized components help reduce operation times bringing cost savings to hospitals and help in recovery of the patient (savings for insurance companies and employers)”

4 CONCLUSIONS

One of the main hot topics in the workshops was **QUALITY** and how it is directly linked to many of the listed needs from shareholders. Each of the shareholders did see benefits for using AM for less critical end use components or tooling for example. Despite seeing possibilities in less critical applications, the Finnish Defense Forces stated in the very beginning of the workshop that **qualification capabilities for aerospace components needs to be acquired within HX-program.**

The target for the Finnish Defense Forces is to produce components for HX-fighters, and later on this gained manufacturing competence can be utilized in other branches than air forces as well, that have components with lower requirements for quality.

To be able to compare different levels of quality during and in the results of this workshop, a tool published in a report "Additive Manufacturing Center of Excellence in Finland" will be used.

In the quality pyramid, moving up a level adds to the requirements for every step of the process, from design through manufacturing, post-processing and testing and inspection, and therefore the skill level and resources required in every level increases as well. The levels are labeled as follows and a visual presentation can be seen in *Figure 12*

- **Level 5 – Extremely critical components to aerospace, nuclear plants, etc.**
- **Level 4 –Critical component – classification needed (PED / oil & gas / etc.)**
- *Level 3 – Critical component with dynamic loads*
- *Level 2 – Data sheet values should be met*

Level 1 – Part needs to be made out of metal

A more thorough explanation can be found in the original report. (https://www.businessfinland.fi/4ada70/globalassets/finnish-customers/02-build-your-network/digitalization/hx-fighter-program/am-center-feasibility-study-2019-nov.pdf)

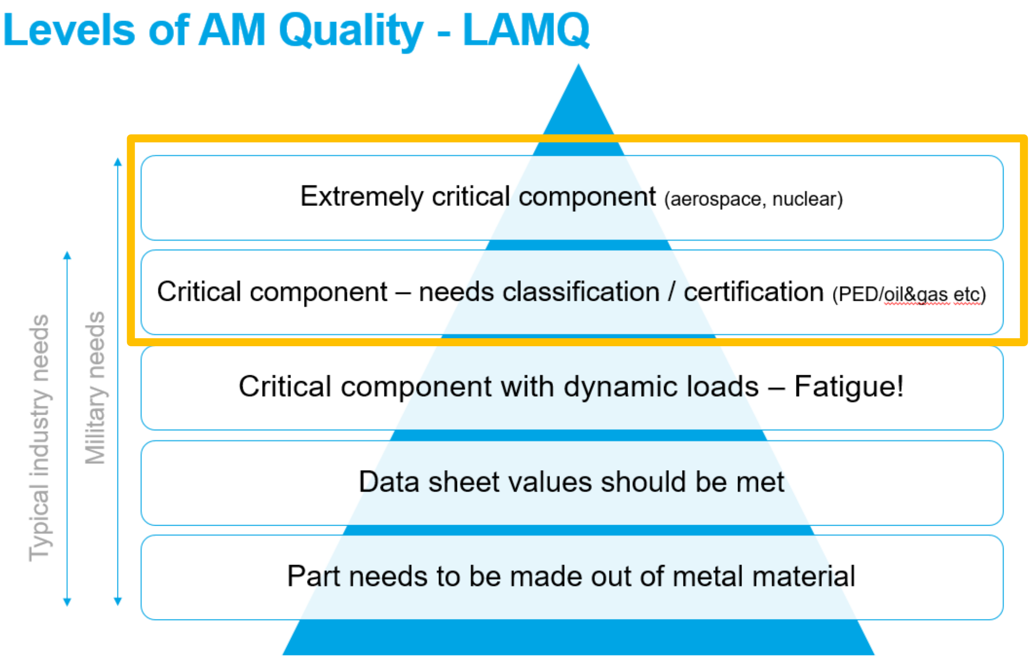


Figure 12. Target level of quality.

When evaluating other than Finnish Defense Forces business cases, participants found that **the competitive advantage for the shareholders could be found from the capabilities gained when operating at the levels of 4 & 5**. This is due to the fact that usually the biggest financial and competitive gains can be achieved in the most critical components which tend to require good quality and reliability. When operating in levels 1-3 such confidence cannot be guaranteed, which is the current state in Finland (most of the AM production equals to level 2).

If the highest levels in the quality pyramid in additive manufacturing are achieved, it would enable

- Best research
- High-end components with better profit margin
- New possibilities for example in energy and medical sector
- Possibility and ease to downgrade production to other levels in terms of required quality
- Taking the best out of the technology

Seeing the interest of the shareholders to utilize additive manufacturing in the highest two levels, a poll was done to find out if this can be reached. It was stated by the workshop participants that without significant investment in AM, Finland will not achieve level 5 in the near future and therefore cannot become a frontrunner in AM. Poll results can be seen in Figure 13.

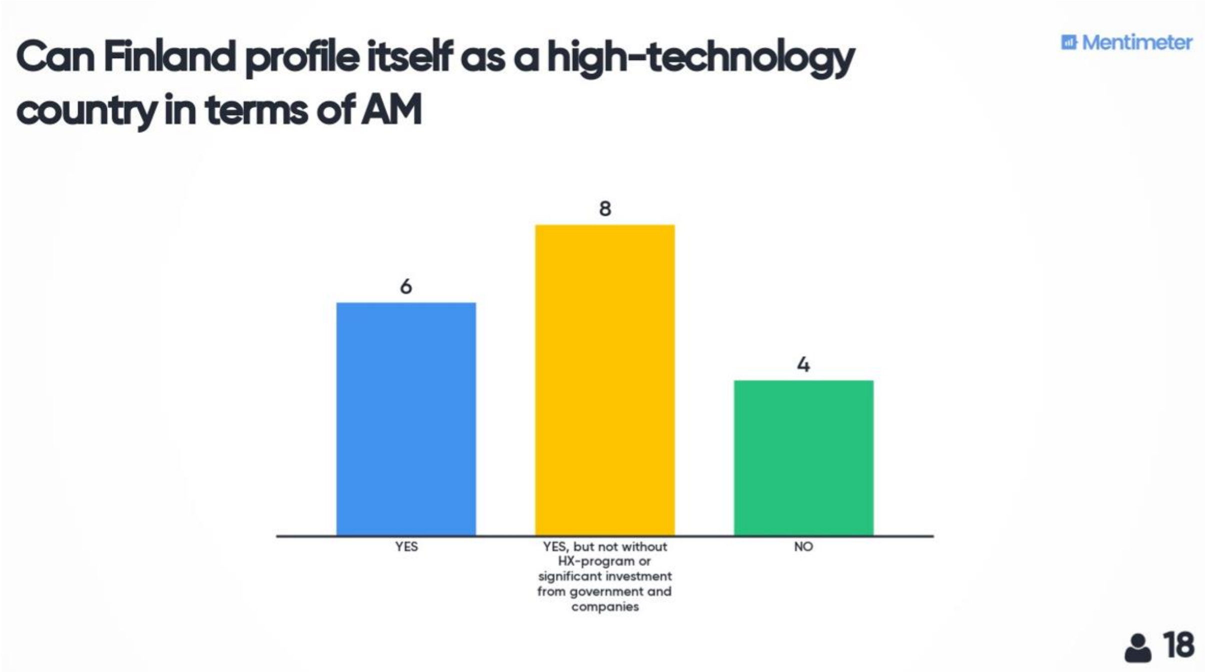


Figure 13 One question of a poll presented for the participants .

4.1 Scenario 1

Capabilities to manufacture "Critical AM component – Level 4" can be mostly built up on information received in knowledge transfer. However it will still require significant investment (time and money) from government and companies.

The existing infrastructure and knowhow in Finland matches level 2 on the quality pyramid (*Figure 12*) and it is safe to say that moving up to higher levels would require knowledge Finland currently does not possess. Level 3 could be reached with investments and research from the additive manufacturing service bureaus and academia.

If we want to reach level 4 and want to speed up the adoption Additive Manufacturing Finland should request HX-program OEM to place:

1. *Knowhow transfer*

Referring to *Figure 14*, below is a high-level list of topics related to knowledge transfer of manufacturing a critical component

- Material data
- Structural data
- General and organized way to move through the entire manufacturing process

- Qualification and quality assurance processes
- Certification knowhow
- Trainings

These are existing or potential bottlenecks in industrialized AM production.

But it's important to understand that Finland must have the capability to adopt the information and start to build own research on top of that. The research itself with limited materials or machines doesn't take us to the highest level.

As one of the workshop participants stated: **"55% of the fatigue data is general know-how, but the remaining 45% is closely dependent on production"**

Companies, with support from the government, could carry on the research with their own investment. Finding out general information and rough guidelines, eg. regarding fatigue data, is a sensible investment and can be done with a feasible amount. But on a high level we can state that with 20% investment we can acquire 80% of the know-how. But the rest 20% of the know-how requires 80% of the investments.

Thus if we want to reach level 4 and want to be able to carry on research and development in Additive Manufacturing, Finland should request HX-program OEM to place:

2. AM research center to Finland

The AM research center would be its own unit providing research and education as well as prototyping capacity from its AM machine side. Critical components could be researched within the center. So the center would have:

- Machines for research and prototyping
- Know-how transfer from OEM

4.2 Scenario 2

Manufacturing of airworthy components requires validated production line. The highest level in levels of AM quality "Extremely critical component – level 5" doesn't allow any variables in production process so every link of manufacturing chain must be defined and frozen.

Qualifying production of a critical component is extremely difficult. Challenges exist in terms of lack of know-how, standardized manufacturing and testing methods, qualified production, sufficient inspection equipment and expertise, material data, and in general an organized way to move through the entire manufacturing process described later in *Figure 14*. Furthermore, there is no such thing as a one-stop-shop for metal AM in Finland, meaning that design, AM production, and advanced thermal and surface post-processing never occurs all in one place.

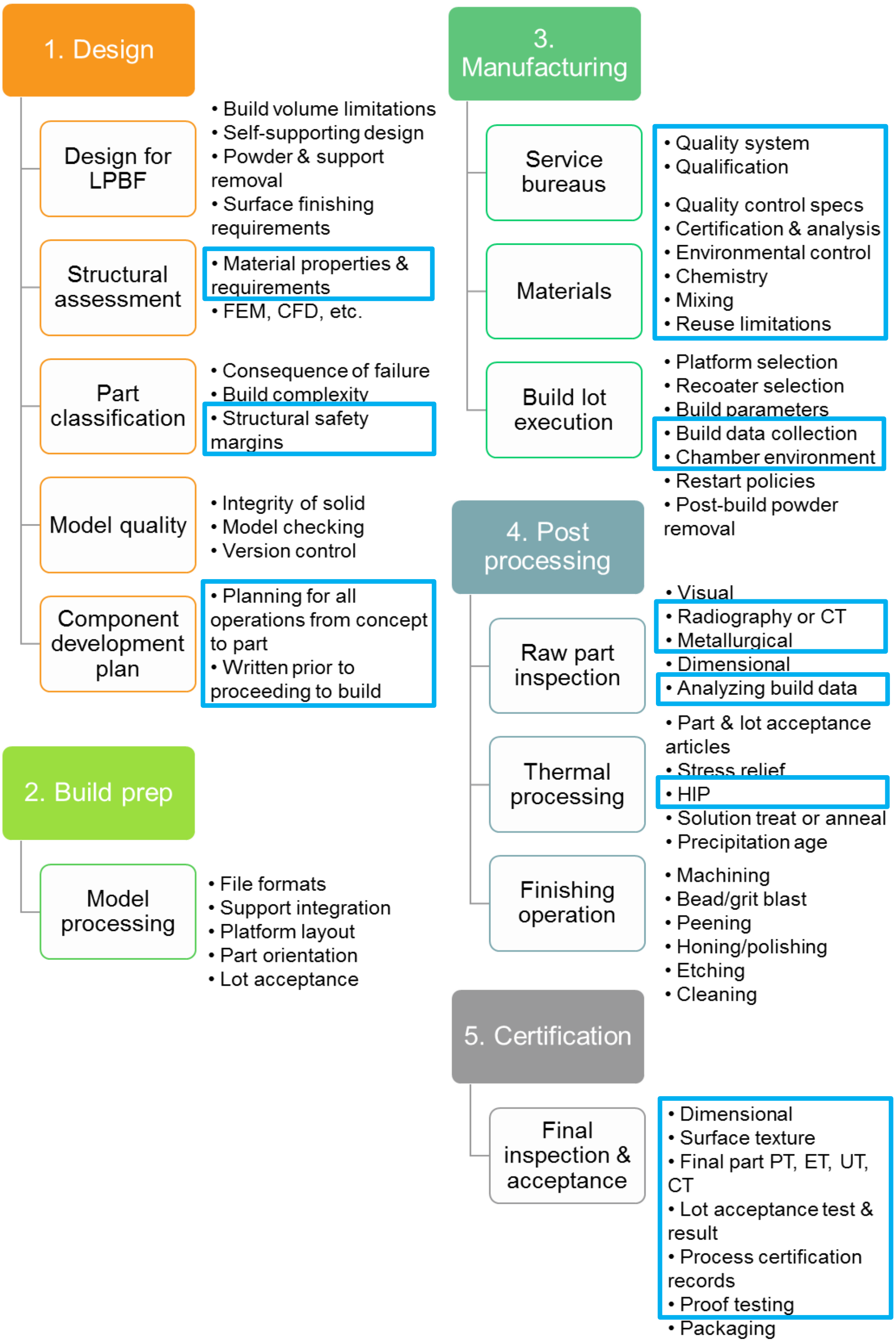


Figure 14. Missing competencies or lack of full understanding that Finnish AM eco-system has when creating a qualified component with LPBF. (Wells, 2018)

In order to tackle some of these problems the only way is to freeze the manufacturing process and limit the variation.

If we want to reach level 5 and want to produce airworthy components for HX fighters in the future, Finland should require HX-program OEM to place part of its AM production to Finland.

OEM could purchase production capacity from Finland where a copy of one of the OEM's validated AM factory's production lines would be implemented. This way both production and know-how could be transferred at the same time. This would ease all validation and certification work needed to make sure the production line is suitable for critical component manufacturing. In the future all changes made to the "mother line" could also be made to the production line in Finland. This could form the base for the AM center of excellence.

A bigger more focused AM center of excellence could serve the Finnish industry in all of its AM related matters up to the most critical levels of AM components. Critical military and aerospace components could be researched and manufactured within the center. The overview of the operation of the center can be seen in Figure 15 and read more thoroughly in the report "Additive Manufacturing Center of Excellence Feasibility Study" mentioned earlier.

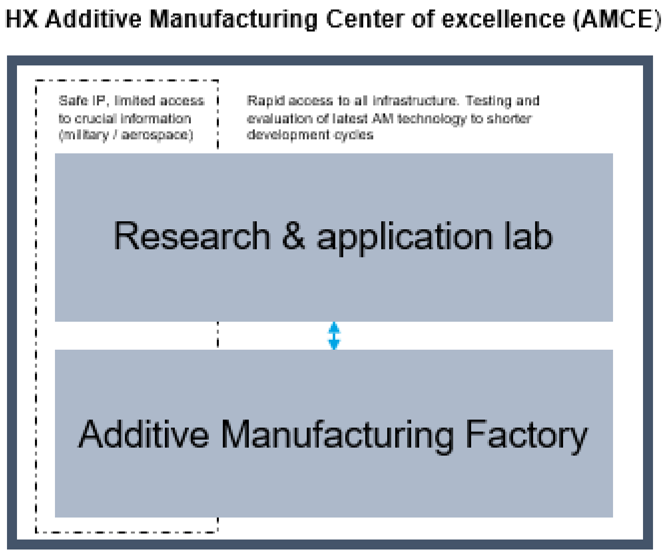


Figure 15. An overview of the proposed Center of excellence

5 FINAL STATETEMENTS

Additive Manufacturing as a technology develops fast. Without one's own continuous development, knowledge alone will not bring benefits that would increase Finland's ability or competitiveness significantly in a long-term basis.

Capabilities to manufacture “Critical AM component – Level 4” can be build up on information received in knowledge transfer. But it will still require significant investment (time and money) from government and companies.

Manufacturing of airworthy components, as required by Finnish Defense Forces, requires validated production line. The highest level in levels of AM quality, “Extremely critical component – level 5”, doesn’t allow any variables in production process so every link of manufacturing chain must be defined and frozen.

If “Extremely critical component – level 5” manufacturing capability is received as part of the HX-program, it enables scaling down the competencies to the lower AM quality levels and speeds up the technology implementation in Finland.

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ETTEPLAN IN SHORT

Etteplan provides solutions for industrial equipment and plant engineering, software and embedded solutions, and technical documentation solutions to the world's leading companies in the manufacturing industry. Our services are geared to improve the competitiveness of our customers' products, services and engineering processes throughout the product life cycle. The results of Etteplan's innovative engineering can be seen in numerous industrial solutions and everyday products.

In additive manufacturing Etteplan combines expertise with our company-wide excellence in the fields of engineering, simulation and mechanical design to offer our customers a comprehensive set of services related to the creation of additive manufactured goods. By choosing the right experts for every project, we are able to tackle even the most challenging engineering or manufacturing problems.

Etteplan has service offerings to help ensure the efficient implementation of AM:

- AM screening – We provide careful analyses of existing products and assemblies, along with creation of business cases to support decision-making and understand the full AM potential of your product portfolio
- AM engineering (adaption or design for AM) – We work closely with the customer to modify or redesign an existing product for AM. For each project we organize a multidisciplinary team to take a simulation driven design approach, using topology optimization, FEM, CFD, and print process simulation during the design process.
- New product development – We work together with our customers to invent new products utilizing the design freedoms of AM to gain competitive advantage and meet future end-user requirements
- AM training – From basic to advanced AM trainings offered on-site, with tailormade training packages from 1-10 days designed for designers, engineers, managers, strategic buyers, etc.
- AM purchasing support – A history of working with an extensive network of service bureaus along with our own AM cost calculation tool means that we can readily help our customers with initial AM purchases while ensuring that they receive a competitive price and high-quality end products
- AM factory consultancy – Highly experienced advanced manufacturing experts will help plan or improve set-up of AM production for R&D, repairs or serial production. Project scope can vary from concept generation and planning through full turn-key factory.

Questions related to report or additive manufacturing in general?
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