The Future of Manufacturing Business:
Role of Additive Manufacturing
Prof. Vaman Kulkarni
Consultant and Ex Director
Honeywell Technology Solutions-Bangalore

Lecture-24
Supply Chain for Additive Manufacturing

Hello good morning, good afternoon. This is Vaman Kulkarni, I was working with Honeywell and I retired last 2 months back. Right now, I am a consultant, I was with Honeywell for last 14 years basically in charge of all the mechanical systems development as part of that additive manufacturing technology I developed in India and we set up a state-of-the-art lab in Honeywell.

Before joining Honeywell, I was with gas turbine research establishment for 21 years and I was responsible in developing the engine controls as well as the performance and simulation for the Kaveri engine. So, that has been my brief background. Today's topic is on the supply chain for additive manufacturing. There is lot of discussions going on today on additive manufacturing and the benefits what additive manufacturing is bringing.

So, because of the here benefits what additive is bringing it is going to make the supply chain that much simpler and then easier for us to manage. So, when I talk about the supply chain, I am talking about the end to end things here, that is once we have the design, we look at all the inputs the raw materials which are required and then go through the complete manufacturing cycle to produce the part and then deliver to the customer.

It could be the internal customer or it could be the final and outside customers. That is the end to end integrated supply chain which I will be talking about and this is as relevant to additive manufacturing and more applicable to the metal which uses the powder bed additive technologies.

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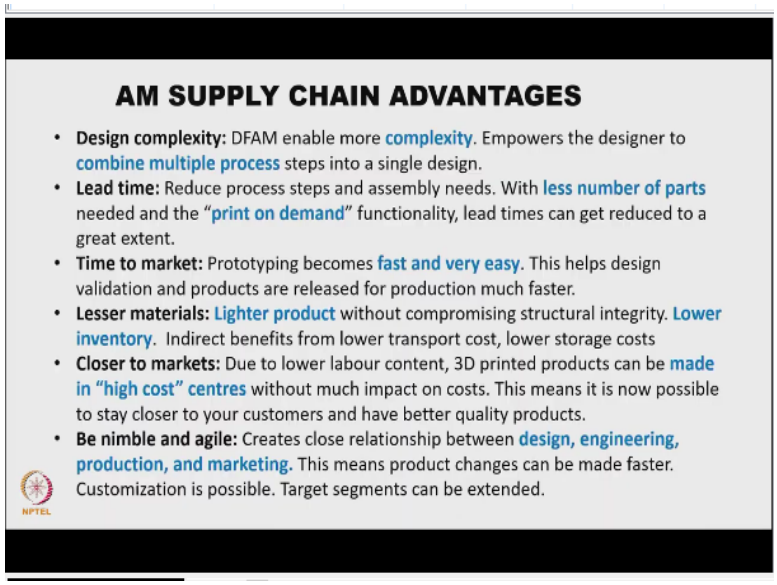

So, when you look at the additive manufacturing what benefits it gives which is related to the supply chain related activities. Definitely additive manufacturing enables the design complexities we can come out with the complex designs which will help in having a better performance and then it combines the quite a few functionalities.

So, it empowers the designer to enable all those things as part of the design, but when it comes to the integrated supply chain it helps in reducing the number of parts. When it reduces the number of parts so the supply chain related activities to that extent gets reduced and we can also do a almost like a print on demand. So, we do not have to take actions to build an inventory of the parts.

So, depending on the cycle time to produce these parts through the AM we can almost do it like a print on demand. Lead times is considerably reduced, when you look at the product development cycle typically in the conventional manufacturing you have the design, you make the prototypes and then you have to test it and then based on the testing you have to modify the design and then again go to the manufacturing cycle.

So, time to market is quite a large contribution with the conventional manufacturing. So, with the additive manufacturing we can quickly make the prototypes, test it, modify the design, print it and then we can take it to the market very fast. This helps to be ahead of our competitors by leveraging the additive manufacturing. Definitely additive manufacturing there is no wastage of material.

We can also optimize the design to be lightweight and it still meets all the structural integrity requirements and because of that we also need a lower inventory of the raw material. So, those are the benefits what additive manufacturing brings because of lesser usage of material. If you look at the conventional supply chain, we always look at the place where we can produce these parts at a lower cost.

And because of that especially in the current situation the parts which are required in US and Europe they are all produced in Asia and that involves lot of transportation. So, whereas with additive manufacturing because it is less dependent on the cost what it can be produced it can be produced anywhere and so because of that we can produce these parts in high cost centres and which is closer to the customers.

Thus, reducing the transportations which is involved. With additive manufacturing we can also be very agile and nimble with the designs, the design engineering, production, marketing they can all work very closely. So, that we can come out with a product to the customer needs and then we can target a larger market segment as part of the additive manufacturing.

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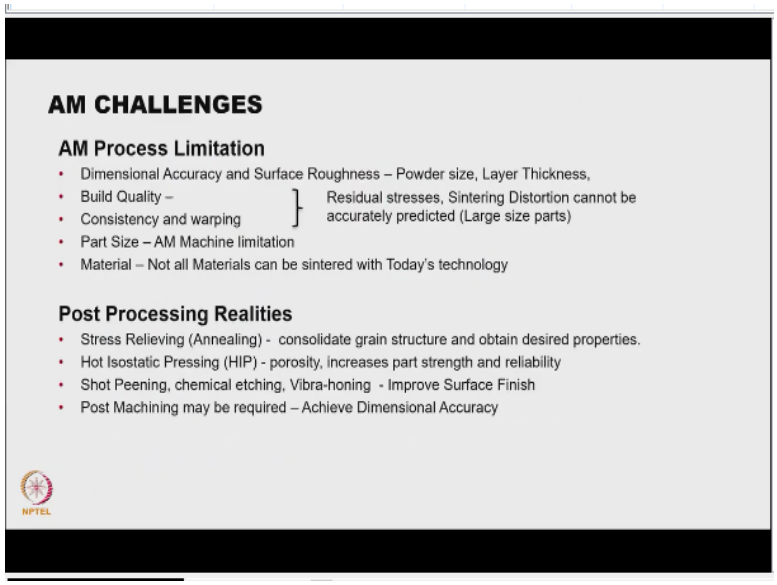

These are the benefits what AM definitely brings to the supply chain related activities. There are few challenges today with additive manufacturing which we need to be aware of especially the part when you produce it out of additive manufacturing. We will not be able to achieve if it is a very close tolerance. Anything which is less than 50 microns is difficult to achieve by additive manufacturing.

So, you may have to do lot of post machining which will be involved and the same thing is true with the surface roughness. The build quality itself; that there are some uncertainties in terms of the build quality which has to be established. So, this build quality is related to the residual stresses which could develop as we print the part. It could be related to the sintering distortions which is difficult to predict it analytically especially in the large size parts.

So, those are the things which the technology is developing and these evolving especially when you look at the critical parts we need to keep these things in mind and the size of the part itself is again a limitation because the build size is the one which drives this. The most of the machines which are available today can build up to 400 millimeter by 400 millimeter height or 500 millimeter height.

But there are machines which are coming out with multi lasers which can increase these sizes but still under development and evaluation and then the material itself there are constraints. What materials we can build especially when it comes to the magnetic material or the hardened steels or the forged materials which is difficult to come out with the additive manufacturing?

There are quite a few post processing needs for the AM build parts. The most important thing is the minimum thing what the part is subjected to is the stress relieving because lot of thermal stresses are developed when we build these parts and then to have a uniform density. We also do a hot isostatic pressing of the parts which is a heat process which we typically call it improves the material strength and then gets a uniform microstructure.

In most of the cases again we do the minimum surface finish related activities like short peening or the chemical etching. So, those are the things which is minimum required on an AM part and in quite a few cases to meet the dimensional accuracies you may have to do some sort of a post machining. So, these are the today's challenges on the AM built part.

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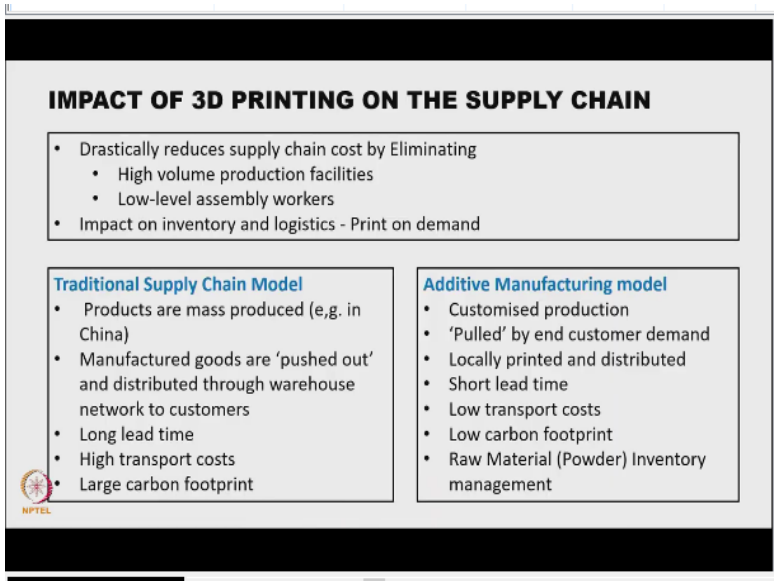

So, what impact 3D printing is creating on the supply chain? So, this is an important question and there is lot of interest shown based on the advantages which I mentioned in my first chart. So, it drastically reduces the supply chain cost by eliminating the high-volume production facilities which is typically there in the conventional supply chain and it almost we have a minimum effort which is required for the low-level assembly.

In most of the cases we will able to consolidate the design and then come out with a design by part consolidations. So, there is a big impact on the inventory and the logistics because of supply chain benefits. So, as I mentioned earlier it is almost like print on demand. So, we do not have to build an inventory of parts because of the cycle time which is involved and similarly on the logistic piece there is very less wastage of the raw material.

The only raw material in this case is the powder. So, we just need to manage the powder and then the part is built out of that and because of the consolidation also there are quite a few examples of part consolidations where 160 parts of a heat exchanger is reduced to just one assembly. So, the number of parts which we need to handle for the full product is also reduced.

So, if you see the differences the traditional supply chain model and the additive manufacturing model have the next few slides which picture really talks about this. The weight of the part is considerably reduced in the additive manufacturing whereas in the traditional manufacturing, we have the weight of the part and number of parts are also higher. Typically in the supply chain type of things we need to manage the inventories.

So, typically we manufacture the parts and then keep it in the warehouses and then from there it goes into the network of customers. This inventory we need to maintain because of the long lead time which is involved in the traditional supply chain model and then we always look at where we can produce it at a lower cost and because of that we have high transportation cost which is involved which adds to the large carbon footprint.

In the additive manufacturing model, it is almost like the customized production even the small changes which the customer wants we will be able to quickly incorporate and then deliver it. So, it becomes a custom thing which AM enables and we do not have to maintain a big inventory. It is almost like on demand we can build the parts because the cycle time involved is very less.

It can be printed locally closer to the customers. We do not have that the entire logistics associated with the warehouse is not needed, there is very less transportation cost which is involved which ensures that we have a very low carbon footprint and the inventory what we need to manage here as far as the raw material is concerned is only powder. So, there is no other raw material which is involved as we manufacture these parts. So, the inventor management of raw material also becomes very, very minimal.

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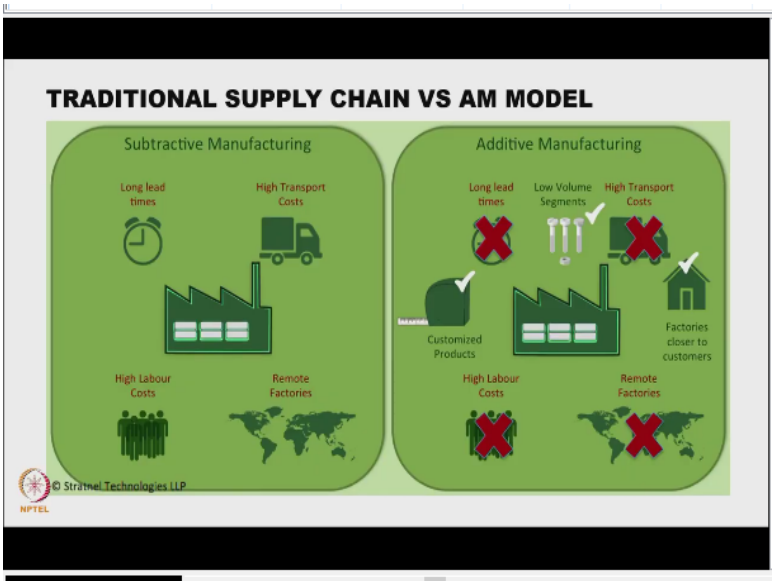

So, this shows the picture really the difference between the subtractive manufacturing and the additive manufacturing. This is a nice chart you can see the things which are marked across in the on the right-hand side which is required in the subtractive manufacturing, large lead

times since we can almost like customize product, we can build it we do not have a large lead time which is involved.

High transport cost we do not have because we can produce these parts locally and then we can deliver it to the customers or the local dealers. The high labour cost because of the lot of assembly which is manpower intensive type of activities which is involved which is minimum in case of additive manufacturing because most of the part consolidation will take care of that.

Then since it is not dependent on the manpower resources we do not have to produce it in remote locations. So, we can have these things where the demand is there for that product in a localized way. The other important input for the additive manufacturing is the CAD model. So, which is a software model and then when we circulate these CAD models there are IP related things which are involved.

So, we need to address that we are having a proper IP protection thing in place as we transfer these models all over the world depending on where it is finally getting manufactured.

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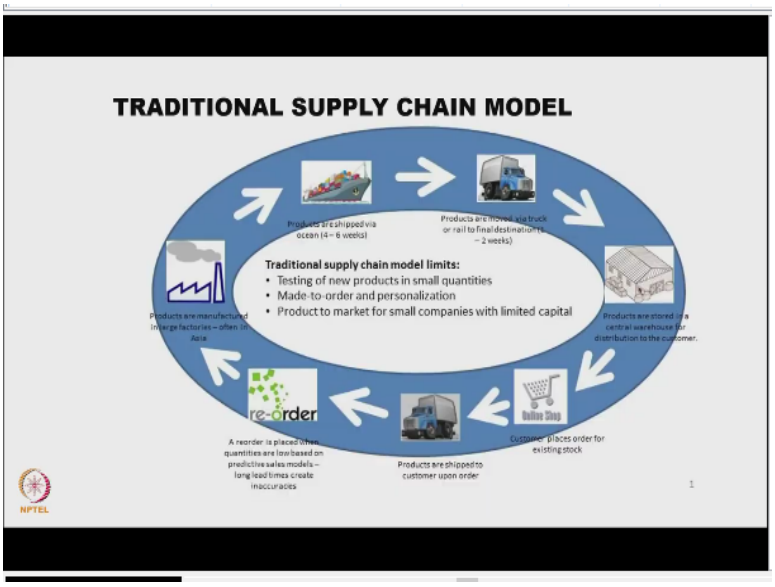

So, if you look at this supply chain cycle here so we can you can see that in the bottom we have the customer demand coming in and then we reorder these parts based on the customer inputs and then when it is typically the minimum inventory what we need to keep to address this the cycle time which is involved in this complete supply chain cycle. So, we based on that decision is made on reordering and the volume of reorder which needs to be in place.

It is typically it is always based on the previous data based on which we decide that what is the volume of reorder which needs to be manufactured and then the products are manufactured in the factories and then since they are done in remote places because of the cost element. It needs almost 4 to 6 weeks to ship it typically through the sea through the ships.

So, it takes almost like 4 to 6 weeks to ship it and then we move it to the warehouses through the trucks which take could take another additional 2 weeks and then they are stored in any warehouse and then we give it to the dealers and then which reaches the customer. So, that is a typical cycle which is involved in a traditional supply chain model.

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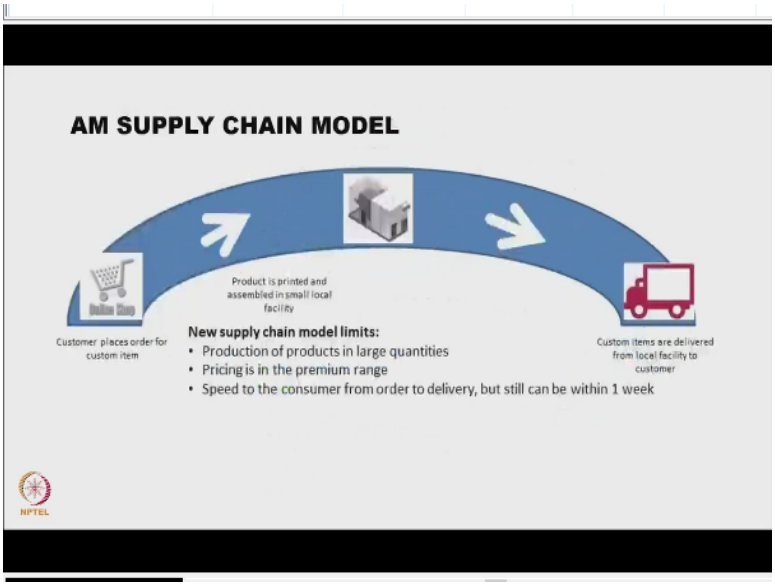

But when you come to the additive manufacturing, so we have the CAD models available, even if it is to be customized with some minimum design changes, we can quickly make those design changes and CAD models can be updated. So, once we have an order from the customer so the CAD models are digitally, we can send it to the place where it gets printed, it could be very close to the region where it needs to be finally delivered.

Because of that we are avoiding the large time involved in the shipping and then the transport and then after the building the part it can be directly delivered to the customer. This customer could be an internal customer where the part is used for assembling along with the other parts and then doing the final testing or it could be or it can get into the minimum inventory which will be maintained to keeping in mind the very, very less cycle time which is involved.

So, that is what is done in the AM supply chain model. So, the typical supply chain cycles the difference between conventional supply chain model and a model is very clearly explained in these 2 charts.

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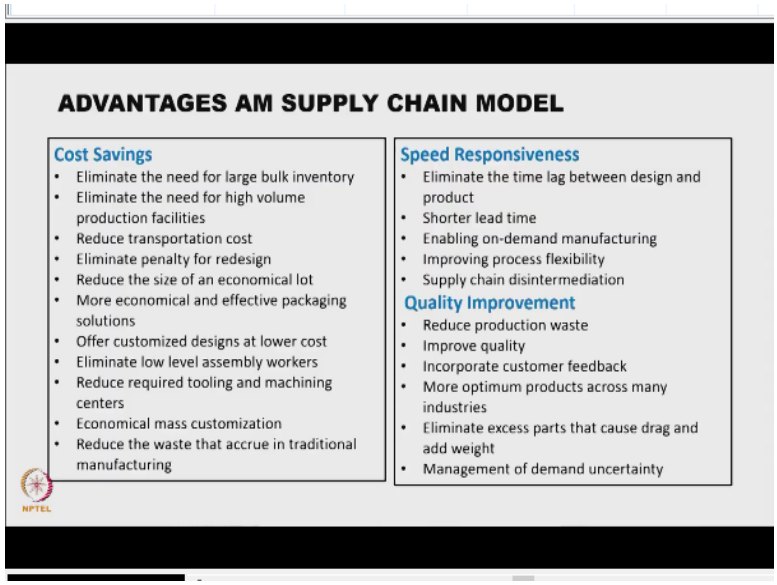

So, looking at the benefits what we get in terms of the cost savings, the speed of responsiveness and then the quality improvement, I will not go through all these bullets, but I will hit the key once which is very clearly a differentiator as far as additive manufacturing is considered from the supply chain considerations. So, the key thing is we can customize the part and because of that we do not have to keep the bulk inventory.

That is going to make a big impact on the cost piece of it and then transportation cost we talked about it is another big savings what we can have from the cost point of view. In the conventional manufacturing there is also what is called as the minimum order quantity MOQ which needs to be done whereas we do not have those minimum order quantities additive manufacturing.

So, we can even if it is a very low volume sort of things, we do not have to unnecessarily build minimum order quantity and then store it and then manage it. So, because of the very customized things what we can offer to the different customers without much impact on the cost piece of it we are able to address the larger customer base with additive manufacturing. In some of the conventional things we may have to manage the tooling's which is required if it is a casting or the forging the dye tools.

So, we need that is another big inventory which we have to manage and it has to be replenished frequently. In the additive manufacturing there are no tools. So, we do not have to manage those tools and that is another big savings what additive manufacturing enables from the cost point of view. The wastage of material is almost nil in the additive manufacturing.

The raw material which we need to manage and then handle is also very largely optimized. So, those are the cost benefits what we get out of additive manufacturing, the speed and the responsiveness. So, because of the way the whole thing is produced, there is no lag between the design and then producing the part.

Once we have the design the CAD models are ready, we get quickly evaluated by the AM manufacturing person and then once we have to go ahead and then he can go ahead and print and definitely the cycle time depending on the part complexities. It is have a very short cycle time. If it is a simple part then conventional things may be taking a lesser time to manufacture.

But almost all the complex parts if you look at it if it is going through a lot of machining processes, if it is a casting and other thing there is a time which is involved in developing the tools and then there is a time involved in producing the part. So, in case of additive there is the time involved is very, very less and we need last minute design changes. So, which can be easily incorporated in the additive manufacturing.

So, that is a big advantage what additive brings with speed. When it comes to the quality related benefits what additive brings it. So, especially for the complex parts the additive definitely improves the quality and any feedback which you get it from the customers. So, that can be easily incorporated in the designs without having any impact on the tools which are required.

Because of the part consolidations any drag in related to the number of parts is eliminated and we can also easily manage the demand uncertainties through in additive manufacturing.

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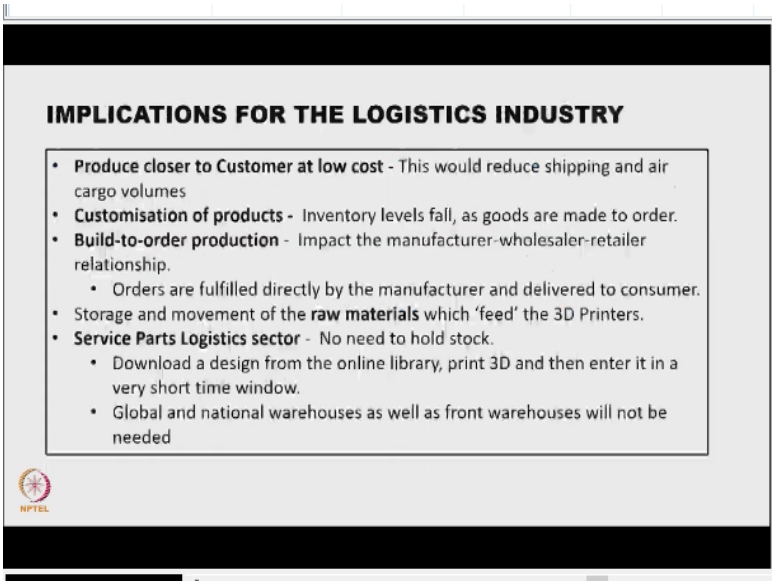

So, from the logistics point of view the impact what additive manufacturing has is definitely the transportation which we talked about a couple of times and then also in handling the smaller volumes because of the customized designs what additive enables. So, that is the big piece of it and inventory management is another big thing which as for the logistics is concerned which additive is enabling.

It almost eliminates the whole sale and retailer relationship, since we do not need to build the parts and then store it in the warehouse and then deliver it. So, since that is not there. So, it is a complete different dimension which additive is bringing as part of that. Managing the raw material is much, much simpler because the only geometry which is involved in the additive is the powder.

We need to just manage the powder and then the other associated logistics which is involved like checking the quality of the incoming material and other things is also simplified. In the service parts logistics, which is typically talks about lot of inventories. So, the way it is done in additive manufacturing is you have the designs ready and then when the customer request we just have to validate the design.

If there are any minor changes you just incorporate on the library of models what we have and then we can send it for printing and then we can deliver it to the customer. So, the concept of the warehouses both global and national things will not be needed as part of the.

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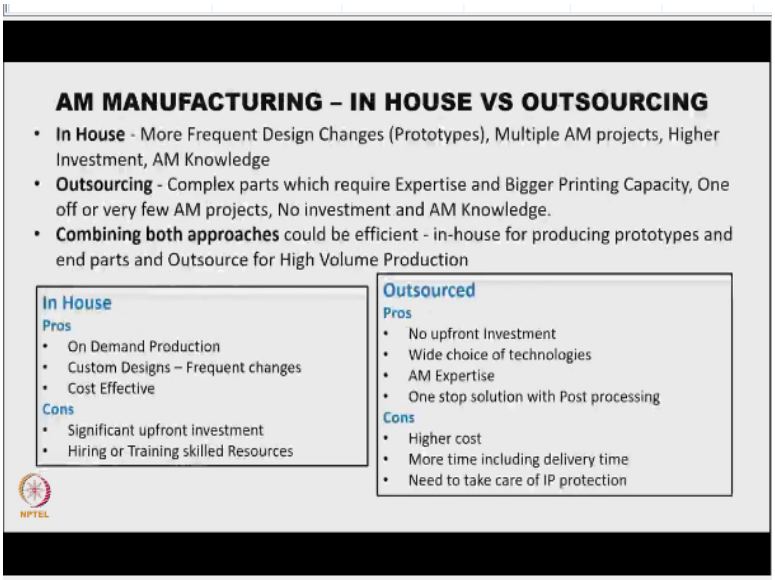

So, that is a big benefit on the logistics industry what additive is bringing. When we typically talk about the supply chain we also relate it to the in-house manufacturing and then the outsourced manufacturing. Even in traditional things we make a decision on make or buy off a part and then we look into the costs involved and the infrastructure and the initial investment and then we make a decision whether it is good to do it in-house or outsource it.

So, when it comes to additive manufacturing a similar decision has to be made whether we need to do it in-house and we need to invest it or we can leverage the services available through the outsourced suppliers. So, if the things which help in making that decision is? If you have a more frequent design changes whether it is a prototype or even a low volume production but the customer needs are having smaller changes which need to be done.

So, that is where additive infrastructure having internally helps because it is easy to incorporate make those changes and then make those prototypes or the small volume production manufactured. But definitely it involves a higher cost and if you have multiple AM projects running in the organization, we need to have that flexibility to build those parts. So, that is another reason why we would like to have an in-house facility to build the parts.

The other associated thing is once you have that we also need to have a skilled manpower who has a very good understanding of the design for additive as well as the manufacturing and the machine related. So, we need to have train the people when we do all this in-house. Outsource things is we are going to depend on the expertise which is available with the

service provider for all the AM related things and then we can take his inputs and then his guidance.

We do not have to build that expertise internally. We do not have to invest for the AM machine itself that is in other the initial interest point of view, we get an advantage by outsourcing it, especially when we have a complex part the expertise available with the service provider could be leveraged rather than building that things internally.

But one thing we need to keep in mind when we outsource it is need to ensure that we need protect the IP things we need to have enough things in place. So, that the IP is safeguarded as part of that and also if you do not have a bigger strategy for AM and we do not have multiple projects running that is the other reason why we think of going it for outsourcing. The pros and cons for in-house and outsourced is sort of covered it earlier.

But it is clearly in-house we need to have quite a few demands for the multiple projects need to have a frequent change in the designs and the custom designs and then we have to it could be cost effective once we have that rather than outsourcing it. When you have an in-house important thing is, we need to invest up front and then also invest on the skilled resources which are required.

For the outsourced manufacturing the advantages are pros are there is no upfront investment which is involved, we do not have to build that expertise of AM. So, it becomes like a one stop solution, he can also take care of all the post processing needs which are required. So, the investment is a big advantage and we leverage on the expertise. But definitely we will be paying for all that .

If you look at the product cost that will be definitely higher in an outsourced manufacturing and it could take more time compared to that if you have done it internally. So, there is a we need to account that as part of the supply chain things and of course IP we talked about, we need to have enough things in place to protect the IP.

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From the quality point of view of how supply chain needs to be contributing for the additive manufacturing, the raw material itself we talked about the powder in this case. So, we need to ensure the powder source which maintains the purity of the powder, the powder shape, the size distributions then the chemistry of it. So, there has to be enough checks in place to ensure that we get the right quality of powder because it is going to affect the quality of the part which you are going to manufacture.

The powder source itself a lot of validation evaluation needs to be done before you finalize on the source of the powder. The other input is the CAD model. So, the CAD model which we give it for printing that needs to ensure that when we translate that into an STL format we do not lose out anything on the geometry. Otherwise, it will realize that only after the part is built, some of those checks have to be in place to ensure that we do not miss out on the quality of the part.

On the printing process itself whether we do it in-house or when to outsource it we need to ensure that the process parameters are monitored in the right way and there is a process in place to ensure that there are no mistakes which happen around that and typically most of the metal printing happens in an inert atmosphere. So, the inert gas which is involved. So, purity of that and then the consistent supply of that that also needs to be ensured it is going to affect the build quality and then of course when we build this part there could be small machine to machine variations.

So, that has to be clearly established and then ensured some validation needs to be done before we do the mass production of this a proper machine calibration and maintenance needs to be ensured. The post processing which is in most other cases the minimum post processing which is involved is in terms of surface finish and then the stress relieving.

So, the machineries and equipments which are used for that and then the proper quality checks on that and then the maintenance of that those things have to be ensured. In addition to that any other post machining has to be done through an approved source especially the HIP process is a key thing which could be involved and then that has to be properly calibrated and then evaluated.

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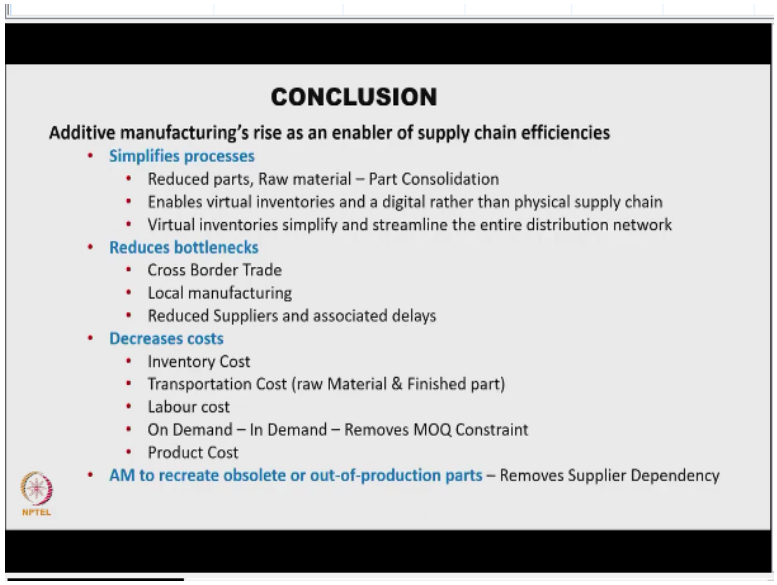

So, with that I come to my last slide as a conclusion piece of it how additive manufacturing is enabling the supply chain efficiencies, the ones which are hitting, which are written in blue are the ones which is really making a paradigm shift in the supply chain related activities with additive manufacturing. So, it simplifies the complete supply chain process itself.

So, either we look at it from the raw material point of view or you look at it from the inventory management point of view. So, it is simplifying the whole process of the supply chain related activities. The various bottlenecks which could be there in the supply chain they are all minimized in additive manufacturing. There are questions which are asked why we need to build this part outside the country?

Why cannot it be built in this place, local manufacturing could be the question which is asked. So, the typical mindset which is there in the supply chain model is identify the low-cost areas and then builds the parts there. So, that constraint is removed and then that bottleneck is no more there and because of that the inventory management as well as the transportation related logistics is all considerably reduced.

Because of the consolidation of parts which AM is enabling we are not depending on multiple suppliers to make the full product. So, the number of suppliers we need to manage is very, very less and then associated delays very less. So, most of those things which are real bottlenecks in the today's supply chain; top type of scenarios is either minimized or completely eliminated.

Cost part of it we had talked a lot about this and then those are the cost benefits which clearly additive is bringing from the supply chain point of view. There are a lot of automobile industries aerospace industries, medical industries, where they need lot of customized parts. They are all taking advantage of additive manufacturing and considerably reducing the medical cost.

The other big thing which additive manufacturing is enabling is how we can create the obsolete parts. The parts become obsolete either because of the upload supplier is not available or here the tools involved in that are not available recreating the tools and then making that partition is a time consuming and it also cost a lot. So, those are the reasons why the part becomes obsolete.

So, and managing that inventory of tools and is another bigger task. We can almost recreate that obsolete parts by just making the 3D model even if the 3D model is not available. Let us say the part is made some 40-50 years back where we would only have the 2D drawings but we can quickly create the 3D model and then we can there is no supplier dependencies involved.

So, we can build those parts, even in some cases out of production parts if the customer really needs it because of various reasons, we can build those out of production parts. So, those are the things which additive is bringing in as part of the supply chain related activities. It is going to a paradigm shift and those are having to be built in as part of our cost models when

we evaluate additive manufacturing as incorporating all the supply chain benefits when we which helps in making that decision.

Of course, I talked about the limitations, challenges of additive manufacturing, we need to keep those things in mind and making that right decisions. So, with that I conclude this topic on supply chain for additive manufacturing typically as applicable for the metal manufacturing. So, that is what I covered. I hope this is good information which helps the making the supply chain decisions as part of additive manufacturing. Thank you. Thanks a lot.