Metal Additive Manufacturing
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Lecture 44
Costing in MAM

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Welcome to the next lecture in the course metal additive manufacturing, in this lecture I am going to talk about the costing in metal additive manufacturing. When I talk about costing it is generally discussed in the first few weeks of the course itself that the cost is quite controlled and there is certain variability that comes for free. So, in a way like in injection molding or any of the conventional or subtractive settings the cost of the mold, the cost of the fixture or the jigs which are designed to manufacture in some specific parts, that cost has to be divided into only to the number of the parts which are to be produced.

For example, using one mole if 1000 components are produced and the mold cost is 2 lakh rupees, 2 lakhs by 1000 per component mold design or mold fabrication cost would be 2 lakhs by 1000 which is rupees 200 but in additive manufacturing with a single machine we can have different kinds of the shapes, different kind of the components, different kinds of the materials. So, this is one of the advantages that it comes in additive manufacturing but still there is a trade-off between additive manufacturing because the time for the processing is quite high for the large number of components still injection molding and conventional Machining, CNC machines is used for the complexity of the parts, a determine fracturing is generally used.

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So, let us have a quick look of what is costing in additive manufacturing. So, I will just discuss for the costing for additive manufacturing then waste identification because the cost is structured in different way. Well-structured costs have the criteria or the structure based upon the fixed and the variable costs majorly. An ill structured or unstructured costs sometimes have very sporadic distribution or the cost is not well defined. Those also we will see then we will see the cost categories like the Prime cost & Factory cost and so then we will see a few cost models. Not a single model we will try to see 1 or 2 models and try to select one best model that suits to the additive manufacturing. In a general setting then what we will see is additive manufacturing cost advantages, which are those and what are the capabilities of a firm with additive manufacturing.

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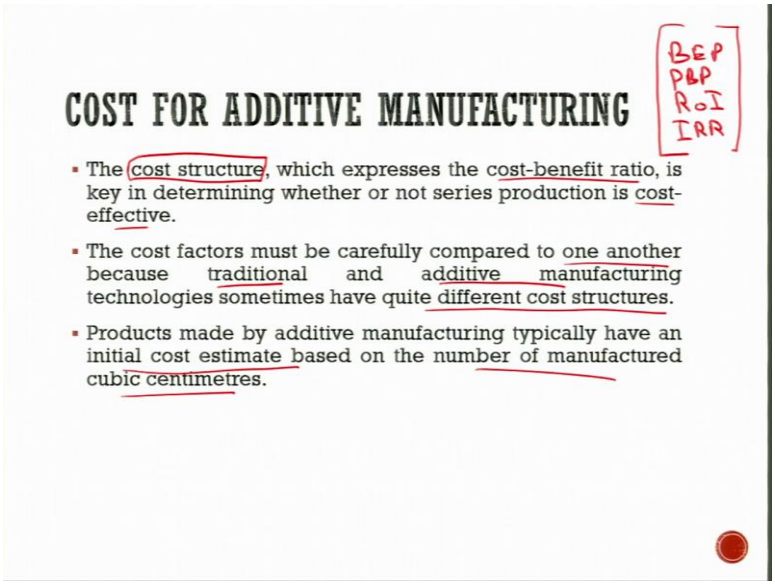

The cost for additive manufacturing, the cost structure which expresses the cost benefit ratio is key in determining whether or not series production is cost effective. The cost structure, that means the keyword here that only tells us whether the production processed we have picked is right to go on or not, whether we have the break-even point coming early, then what is the payback period? when do we get the return on investment? So, all these different criteria are there to determine the cost.

So, we have break-even point, we have payback period, we have return on investment then we have internal rate of return, there are certain criteria to determine that what we have invested, when it would be returned back, the cost factors must be carefully compared to one another because traditional and additive manufacturing technologies sometimes have quite different cost structure, this is only the point of discussion in the lecture series on the costing on matter additive manufacturing.

Products made by additive manufacturing typically have an initial cost estimate based upon the number of manufactured cubic centimeters, that is what is the size of the component that is manufactured for conventional technology. Fixed costs are only allocated to a specific component design as it is said, but in additive manufacturing it is more cost of it because the overall machine, throughout the life of the machine or the printer whatsoever components are manufactured, the cost of the machine is divided into all those. However, the cost of the machine is the biggest contributing factor if you see the cost of the machine comparing to the consumables, the cost of the machine would be quite heavy.

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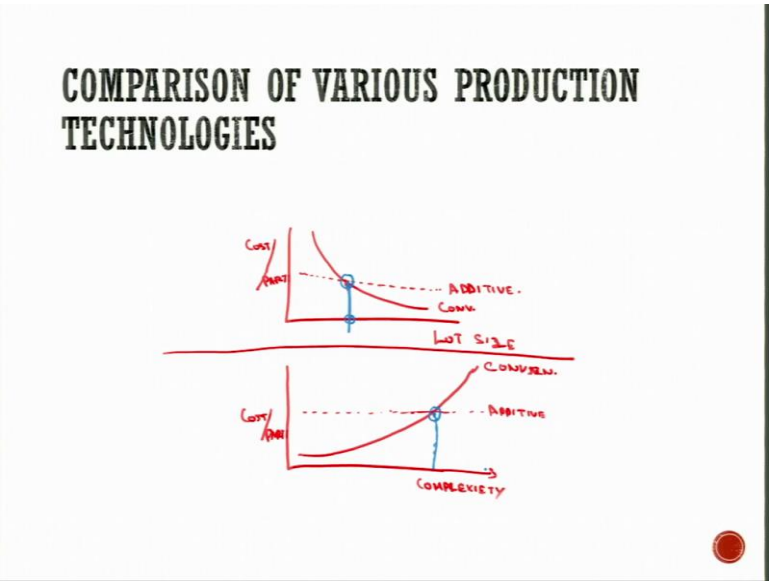

A retainment fraction also involves the fixed cost and the variable cost. Fixed cost generally is the cost of the machine or cost of the investment, cost of the land that you have got or the office that you have got if it is rented that comes in the variable cost, these factors we will just see. So, to compare the cost if I try to draw the clear perspective in that for conventional machining the cost would be just like this, this is conventional for additive instruction. For example, it is some cost, I will just draw a dotted line in this this is additive. So, this is again the cost per part and these are the number of parts or I would say lot size. Now, in this case you can see at this point, specifically at this size of the lot, the cost is common.

So, but further the conventional machining takes an advantage of the lesser cost however still in this additive manufacturing for the product complexity, if the product is more complex, example if I put there again cost per part and the complexity, complexity of the components, if it is in this direction for the conventional machining, for the lesser complex parts, the cost would be high and for the more complex parts, the cost would be lesser. In this case this is conventional, conventional machining and additive manufacturing for the complex parts and for the very simple parts, the cost still remains same, this is additive, in this case, it means for the lesser number of the parts.

The conventional machining is better and only at this point at a little larger cost, when the complexity could not be handled very easily by that conventional machining, that additive manufacturing has a benefit. So, this is how when we can compare the additive manufacturing with the subtractive or the normal regular Technologies. So, here the

complexity generally comes for free because any complex parts could be put into the machine.

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Next is the waste identification, there are certain reasons or certain points or certain leaks where the waste happens in the cost, that is why the costs are to be structured well. So, that we control the waste it has to be lean as far as possible. So, overproduction is definitely one of the point where the components which are produced more than what is demand is. So, that is the overproduction it happens when more is made than what customers need right now.

So, that brings the inventory cost, that brings the storage cost, that brings the material cost that is the material that is used in inventory or in production. Then shipping costs are there. So, shipping does not change when the product is anyway and is a source of risk for the product as well. So, shipping costs also, certain points could be there, where the waste identification has to happen. So, in what lot size is the product could be shift. So, what should be the packaging?

So, all these points are to be taken care of while shipping. Reworking and Defects, more the number of defects, more is the rejection of the lot size, more is the cost or most is the waste in there. Then Over-processing, when work which is not required that is, it is not pre-planned, something comes catastrophic, some post-processing has to happen or some Dimension goes wrong it has to be worked again. So, this becomes the over processing of the components or whatever we are trying to produce. Then the Motion, motion means unnecessary motion, waste of time and money like the material handling within the system what is the material

handling system where to store the system. Is it close to the machine? where it is or what is the availability of the material at different points?

So, this becomes another waste identification point, where we can see whether the motion is quite controlled or not. Inventory definitely includes the costing in itself, inventory is always known as the necessary evil. The required amount of inventory is necessary to fulfill the demand because losing the demand and losing the customer in itself includes a cost or putting more inventory also includes the cost of the investment of the raw material.

So, inventory costs are to be controlled putting the economic order quantity and to see the economic order quantity with price breaks and so certain models are there. Waiting, when the customers and equipment are waiting for materials and parts, these resources are being wasted. So, waiting is also a cost that is to be taken care of.

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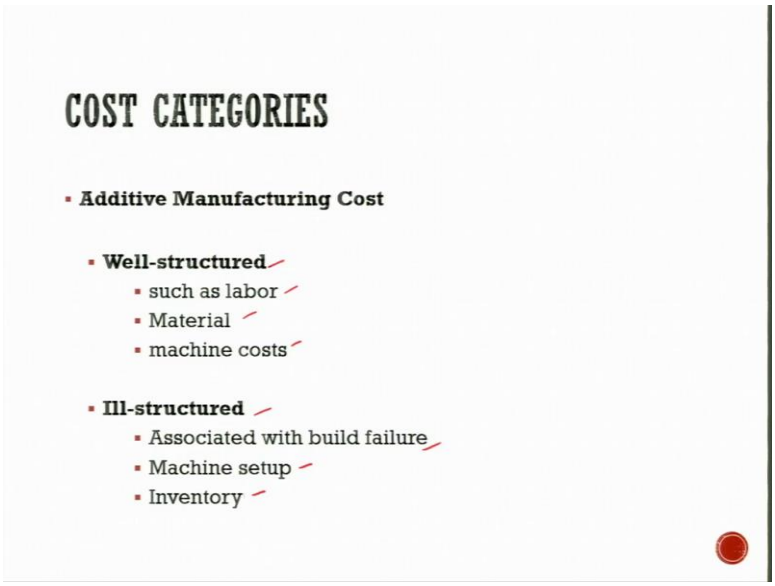

To look at the categories of the additive manufacturing cost it could be well structured, it could be ill structured. Well structures cost would be labor, material, machine cost clearly delineated, clearly differentiated, at what cost what investment is there and how do we try to see and allocate them. Ill structured is associated with the build failure that the component of the product that we have produced fails in between, the spool is finished in between. Suppose it has to be a continuous manufacturing, but spool is finished in between.

So, it has to restart sometimes that fusion does not happen properly. So, that becomes a weaker point, it can break from that point. Then machine setup cost, sometimes the machine setup this is again if the spool is finished that means machine setup has to come be done

something in between the manufacturing itself. So, then that becomes a machine setup that is again a structured cost. Inventory as I just discussed in the previous slide.

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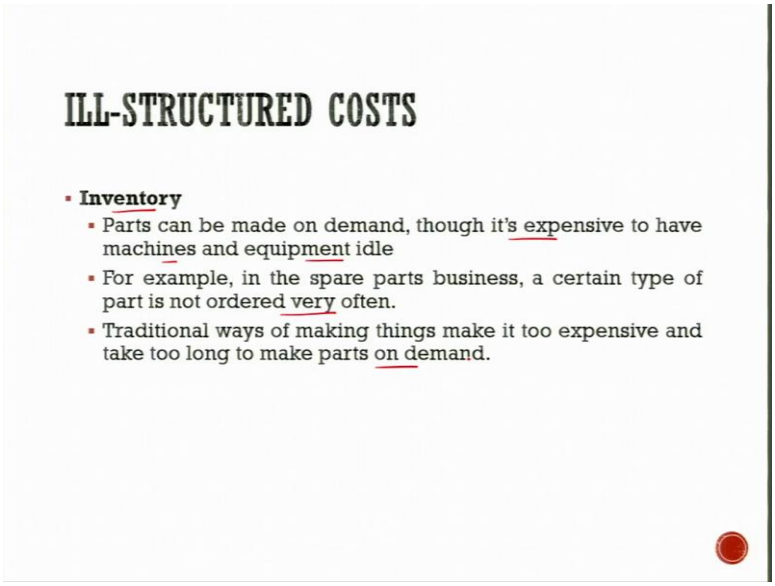

Starting from inventory itself the ill structure costs. So, parts can be made on demand though it is expensive to have machines and equipment either for example, in spare part business a certain type of part is not ordered very often traditional ways of making things make it too expensive and take too long to make parts on demand. So, that is why the parts are to be kept in reserve which is known as inventory.

Now, there is a lot of stock of parts that do not get order very often, this becomes an ill structure inventory cost, this inventory is holding on to the money for the products that are not being used and it takes up again as I said it takes up space, it takes a building, it takes up your land, it has the costing of maybe renting utilities, Insurance of the components taxis along with this the products are also getting worse. Inventory sometimes is not completely nonperishable products.

There is rusting there is a processing on the products that some sometimes has to happen, the packaging of the material, the conditioning of the room if for example, air conditioning is required for the components to be kept for the metal detracting material to be kept, the spools to be kept sometimes that has to be kept in a control temperature control pressure. So, that conditioning or all the inventory cost then using additive manufacturing to make these parts on demand eliminates the need to keep a large inventory and cost that come with it. An additive manufacturing helps us to make the path as an one required. So, that inventory cost sometime is eliminated here.

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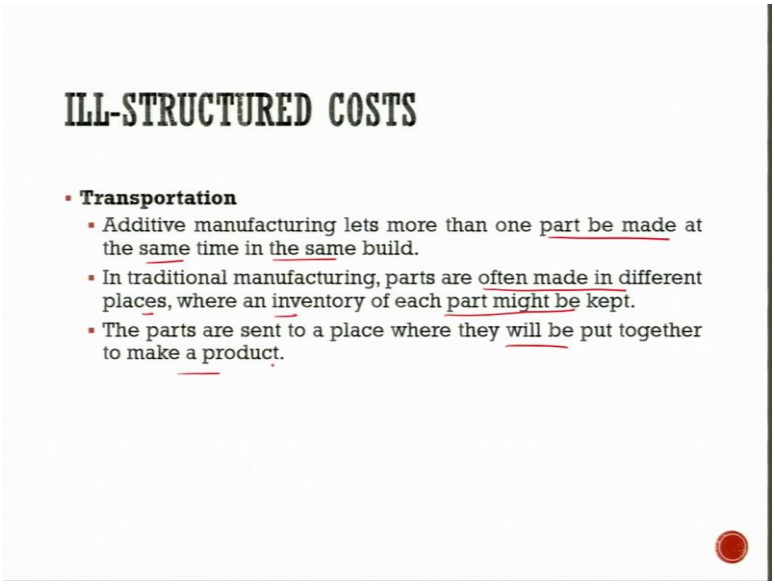

Next comes the transportation, additive manufacturing lets more than one tough part to be made at the same time in the same build, this makes it possible to make a whole product in a one go. In traditional manufacturing parts are often made in different places, where an inventory of each part might be kept then those are to be transported from those places to a single saddling point, a single saddling location, the parts are sent to a place where they will be put together to make a product.

So, transportation in additive manufacturing could replace some of these steps for some products because it could make it possible to manufacture the whole assembly at a single location, just at the printer, where we are trying to produce the whole component in one go or we are trying to produce all the parts and try to assemble it there itself, this is how the transportation cost is reduced, next is this would also make it less important to keep a big stock of each part of a product, it also cuts down the need for just in time delivery and the transportation of parts made in different places.

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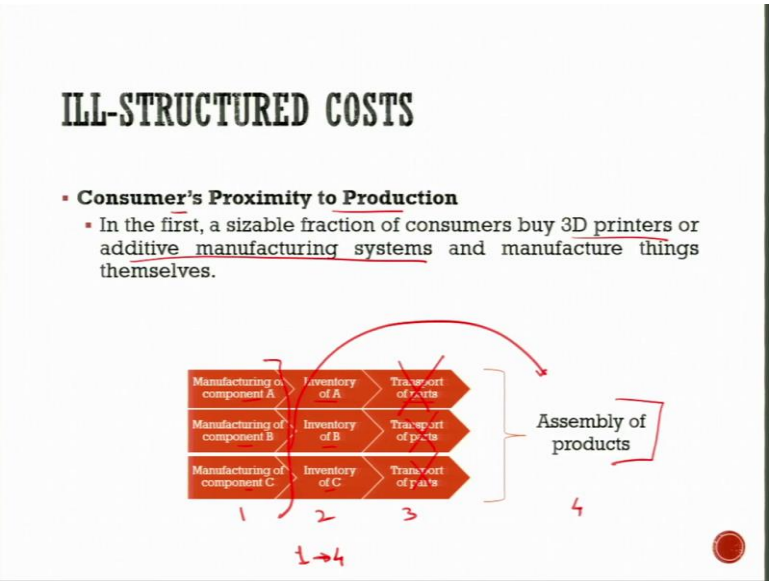

So, transportation also becomes an important cost to be considered. Next is consumers' proximity to production. In the first sizable fraction of consumers buy 3D printers or additive manufacturing systems and manufacture things themselves. So, that means infecting of component A inventory of A is their transport of part induction component B manufacturing component C inventory B this is generally assembly of components in a traditional manufacturing but in additive manufacturing what we do the second case is where this transportation is eliminated you may structure all the components of A B C here itself and from here itself we do the assembly if I call it step 1 2 3 and 4 directly from step 1 to 4 we could go while in additive manufacturing.

So, this is the second step in which customers submit their designs to a company that makes their products. Now the third scenario could also be there where commercial manufacturing sector adopting when the team manufacturing which could alter the design and Production Technologies that also happens in this case.

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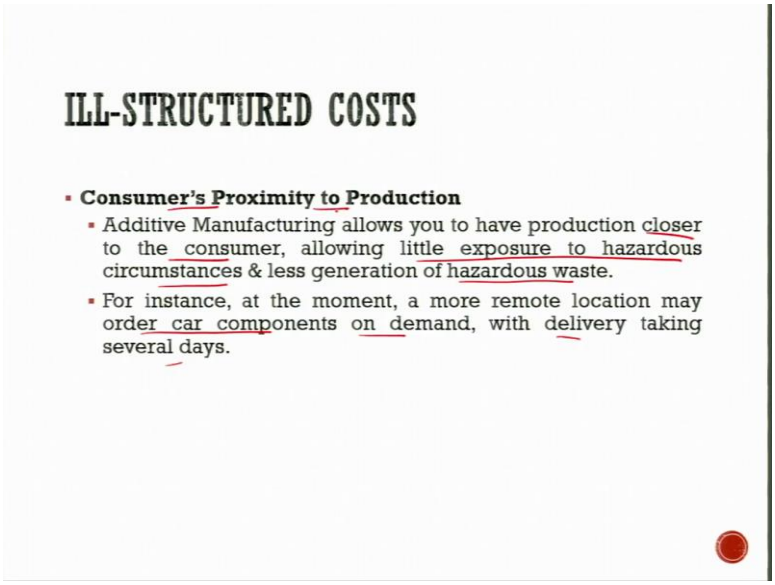

So, consumers proximity to production in additive manufacturing it allows you to have production closer to the consumer allowing little exposure to the hazardous circumstances and less generation of hazardous waste.

Now, this could be a fourth possibility for instance at the moment a more remote location may order car components on demand with delivery taking several days. So, some of these components or goods may be able to be created on site or even close to the point of use then this is a big thanks to a dream infection once again on the top of it the distinction between the manufacturers the wholesalers the retailers may start to become less clear as a result of localized manufacturing against team line procedures because each may be able to make goods in their facilities. So, the distributor or the retailer itself can manufacture and send the components for or use the components or repair the components as and when required. So, this becomes consumer's closer proximity to the production.

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Next is again because I am talking about distribution supply chain management the cost has to be structured rightly here the purchasing operations distribution and integration are all parts of supply chain locating product suppliers is a component of purchasing demand planning forecasting and inventory are all part of operations. So, in the supply chain management while integration entails building an effective supply chain distribution involves the transfer of items.

Cost can be reduced by reducing the requirements of these activities efficient management of the supply chain is largely responsible for the success of some multinational corporation and Merchants. So, that is why supply chain management, green supply chain management, additive supply chain management different kinds of the concepts have been embarked upon by various management researchers and thinkers and various models have been developed on these as well. So, these have innovated how they track inventory and restock shelves using technology which has led to the lower expenses.

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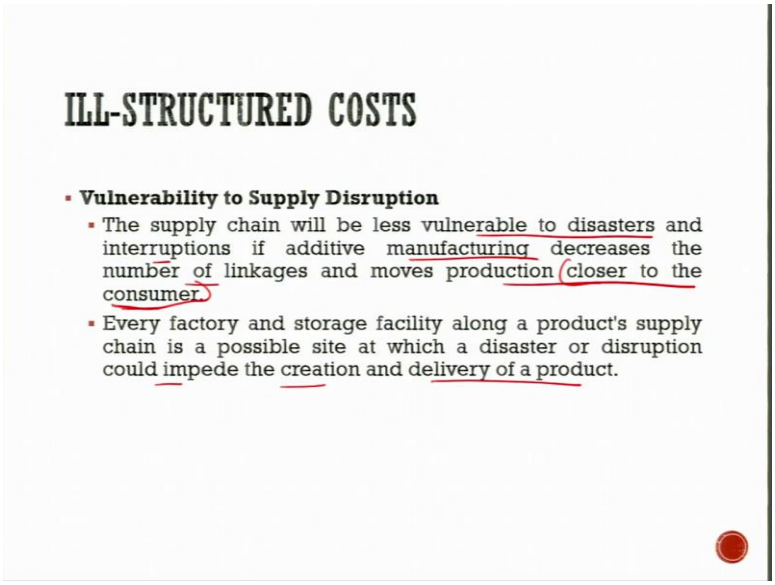

Now, vulnerability to supply disruption this is the direct relation with the supply chain management as well if there is deception in the supply the vulnerability to the disruption is high in the otherwise than additive infection systems supply chain will be less vulnerable to disasters and interruptions. If identity manufacturing decreases the number of linkages and moves production closer to the consumer let us mark these words. Every factory and storage facility along a product supply chain is a possible site at which a disaster or disruption could impede the creation and delivery of a product.

So, there are fewer possible disruption points in a supply chain with the fewer links and smaller overall size which is possible in additive manufacturing and additionally if the production is moved closer to the consumer production will become more decentralized with number of facilities producing a small number of items rather than a small number of facilities generating a large number of products. So, this impacts from supply chain disruptions may be localized than the regional or global systems.

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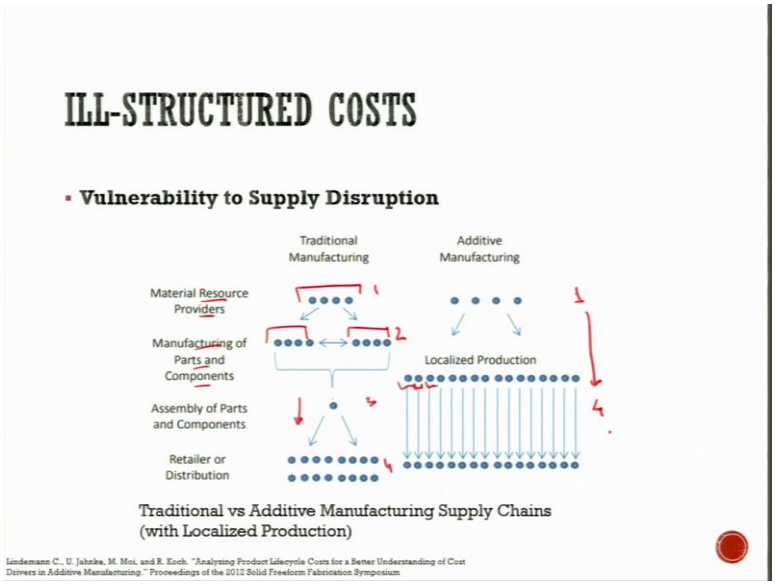

The vulnerable supply chain how is it in the traditional and in the editing manufacturing setting, in a traditional manufacturing setting if you see here manufacturing resource providers are there are 4 traditional reflection systems are there then manufacturing parts and components there are other systems with which they interact the assembly happens at only a single place and this assembly is now distributed to different details for distribution this is how it goes but in additive manufacturing you can see this 1 2 3 4 levels are there it has directly gone from 1 to the 4th level that is additive manufacturing localized production like we get only printers from them and try to produce them localize here and we directly come to the consumer we do not have any redundancy here.

So, a problem at any step during manufacturing assembly could cause deliveries to be at the retail distribution to be delayed. So, localized additive manufacturing does not share the same vulnerabilities. So, the first possibility is that no parts or components will be assembled and directly we get it from the localized production.

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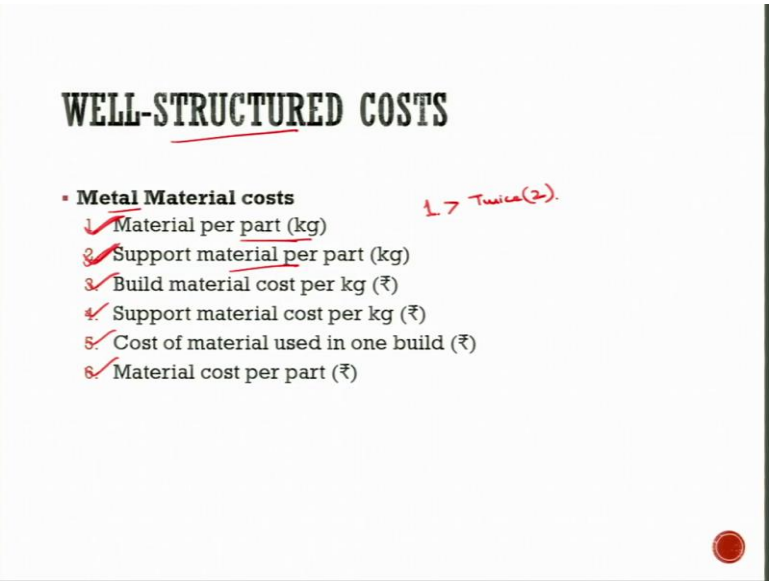

Now, next comes the well-structured cost I have just listed a few well-structured cost based upon the material, based upon the machine, based upon the labor and some other parameters later I will come to the general cost structure a manufacturing and try to discuss about the cost structures specifically in additive manufacturing. In the well-structured costs, the metal material costs if I say there are certain costs such as material cost, labor cost, machine cost another. In the material cost if I am talking about specifically it could be kilogram of the material per part or the kilogram of your support material per part.

So, this kilogram of the material per part would be my metal material let me say the stainless steel. So, this cost 1 would be generally greater than even the twice of the cost 2 this is cost 1 this is cost 2 next comes the build material cost per kg when we purchase spools of the pulled material or the support material it is purchased in the spool per kg it does not give the spool length it is generally this spool per kg. So, this cost is quite heavy if I say the cost of the build per kg versus causes support per kg this again will cost would be quite heavy now this comes the cost of the material used in one build the material cost per part this is only we are talking about the material which is the built material and the support material and the costs are divided into different categories.

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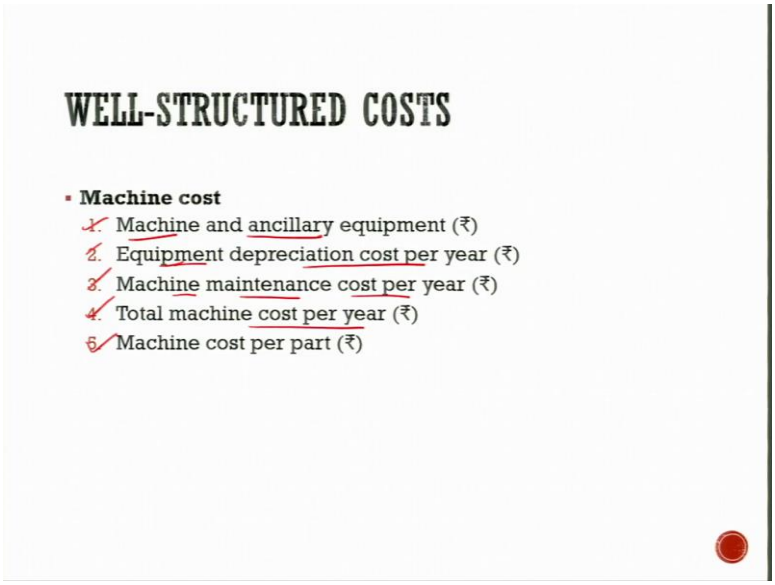

Next comes the machine cost first is a machine and ancillary equipment cost then we have equipment depreciation cost per year. So, each year what is the depreciation along with the depreciation we need to get the maintenance we need to get the extruder head cleared we need to get the maintenance of the machine the components the different moving sliders cleaned and regular the annual maintenance contracts are to be written that becomes also the third component here the total machine cost per year which is the sum of the previous cost and per year it is calculated the machine cost per part. So, the machine cost per part is taken into the calculations and this is distributed towards or along the life cycle of the machines or the all the components which are expected to be produced using this specific machine.

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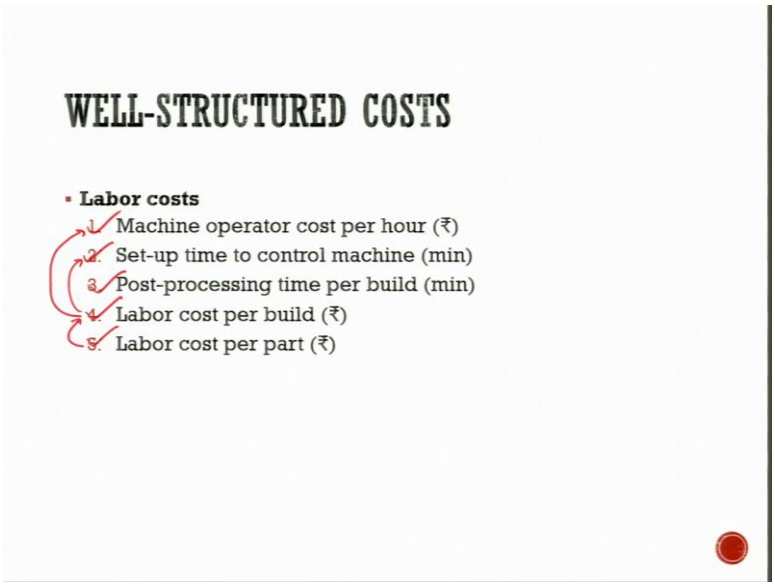

Next come the labor cost the labor cost is the machine operator cost per hour first thing set up time to control the machine is a second factor then we have post processing time per build, labor cost per build, labor cost per part obviously the labor cost per build would be taken from the machine operator cost and the setup time that it takes labor cost per part is again taken from the labor cost per build itself. Build time plays an important factor an important role in this build time is a significant component in regard to estimating the cost of a retain manufacturing and number of software packages are there as I showed you the Iger software in the previous weeks here which gives the estimated build time and based upon the build time taking the material cost into the consideration it also gives us the cost of the part.

So, there tends to be 2 approaches to estimating the build time number 1 was the detailed analysis number 2 is it parametric analysis the detailed analysis utilizes the knowledge about the inner workings of the system while the parametric analysis utilizes the information about the process time the characteristics such as layer thickness or so the different kinds of systems are there to understand the time of the build.

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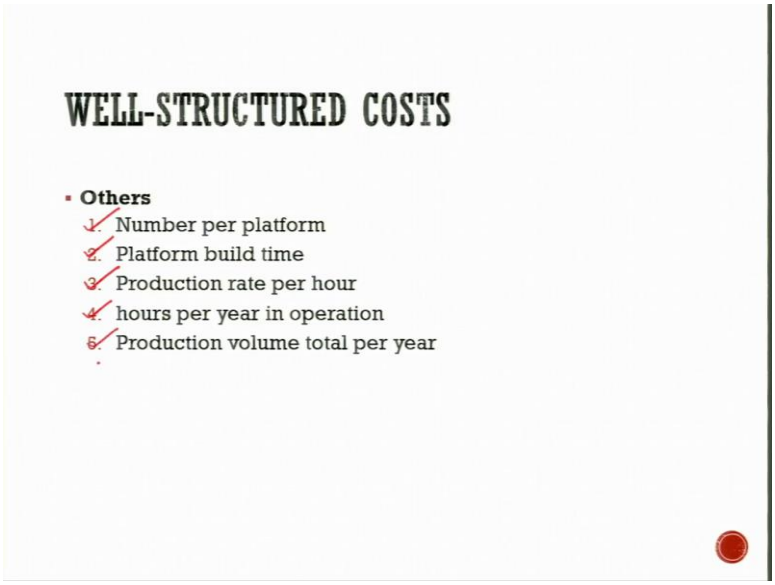

Next come the other components of the cause such as number plat per platform and how many numbers of the components could be put in single platform the platform builds time itself, production rate per hour, hours per year in operation that is the working hours of the company for example, for an 8 hours working day what is the time when the machine is actually working.

Let me say for 7 hours if one-hour break is there but if we run the machine in the 24 hour shift still machine has to wait for a few time in between for the brakes. So, what is the total

number of hours per year in an operation may be considering 20 hours per day machine is working and the Sundays are off 6 days a week. So, 20 into 6 into the number of months that is 12 this is the total number of hours the machine has worked in a year production volume total per year is another factor.

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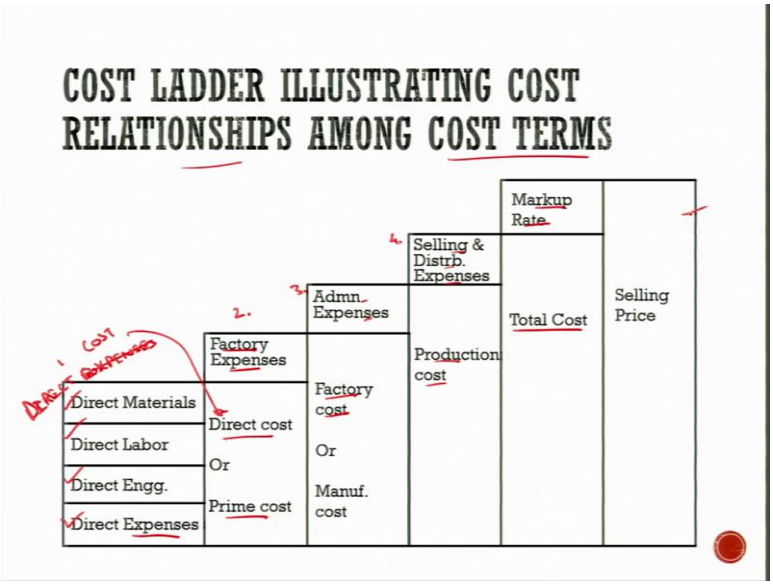

Now, this is the primary cost ladder which illustrates the relationship among the cost terms if we talked about any estimating and costing procedures in the manufacturing Sciences you will generally see these terms definitely one is the direct cost these are the direct cost you can see the word direct written here, direct expenses I would say direct expenses. Then we have second is the factory expenses third is the administrative expenses then selling and distribution expensive all those collecting together gives us a total cost of the product then we have the markup rate that is the selling marketing and everything this gives us the final selling price.

Now, direct expenses include the direct materials, the direct labor, the direct engineering, the direct expenses which are there inculcated into the system because expense is written here I will write here x direct cost. So, direct material means material that you can see directly that I can touch for example, in the direct material I can see stainless steel is there Ceramics sometimes your Ceramics is in itself here is directly active material as well but sometime it is also taken as indirect cost because we cannot directly see them then the factory expenses.

So, it is direct cost or primary cost that is written here. Factory expenses are the rent of the factory, the electricity, the other factors those are add to get the factory cost here next we get the factory cost, factory cost plus the administrative expenses administrative expenses means

the documentation, the rent of the… or the salary of the gatekeeper or for the other people who are not directly involved in the manufacturing that gives us the administrative expenses. Now, the administrative expensive added to the factory cost gives us the production cost. Now, production cost when are is added with the selling and distribution expenses gives us the total cost of the product and with the markup rate at the profit level the selling price is taken.

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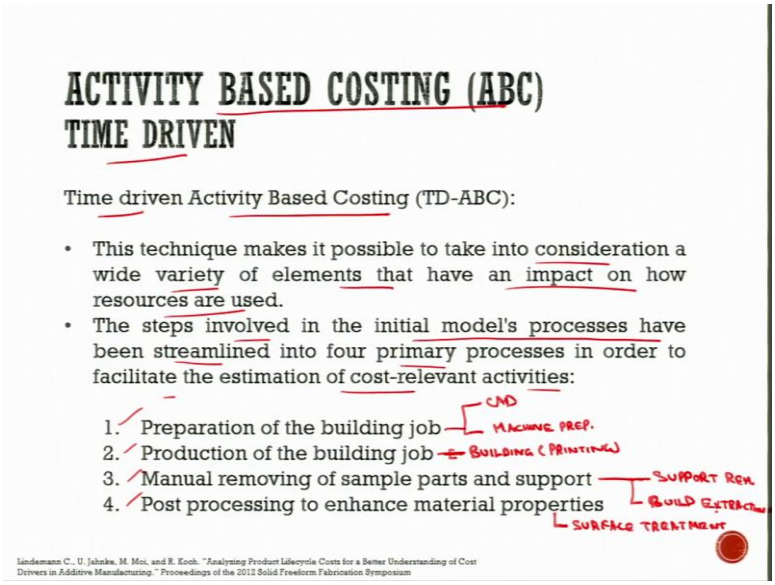

This is the general cost ladder and then a very general criteria of costing is activity based costing we call it ABC criteria whenever manufacturing costing is taken or seen ABC criteria is the base criteria that is always seen first to understand the system later the detailed models depending upon the kind of the machines that we have depending upon the kind of materials being used number of printers which are being installed the kind of the setup changes the different models have been suggested by different researches but ABC is a very basic model to understand.

So, it is a new model known as time driven ABC this technique makes it possible to take into consideration a wide variety of elements that have an impact on how resources are used the steps involved in the initial models processes have been streamlined into 4 primary processes in order to facilitate the estimation of the cost relevant activities. So, the activities which are cost relevant which are given here are preparation of the build as first then production of the building job, manual removal of the sample parts and support then post processing when I say preparation of the build this means the CAD is part of it computed design preparation and the

preparation of the machine, machine preparation and production of the building job production of the building job is building the process actually.

So, this is generally the processing or the actual I would say the 3D printing here that happens here I would generally say building, building or I would say printing. Then manual removal of the parts in which number one removal is the support, support removal then we have to remove the component the build extraction I would say build extraction then comes the post processing in the post processing again this support has to be clean further and in this the support has to be completely removed and the surface treatment sometimes has to be taken care of there are different kinds of the treatments which are there in the post processing. So, it could be surface treatment Vapor smoothing could also happen. So, like different kinds of then we have definitely the quality control as one of the 4 system itself in with the verification and documentation also happens.

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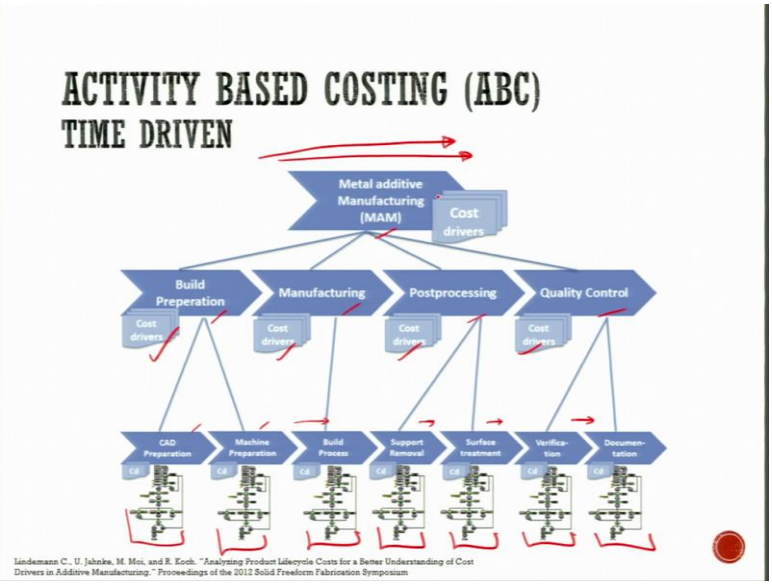

Now, this is how it is mentioned in this illustration as well here that in materiality manufacturing the build preparation is there, then in which CAD and machine preparation is there when manufacturing post processing quality control and the same processes which I mentioned in the previous slide are mentioned here and for each of them there is a separate process in itself it is a process it has a steps which are to be laid properly before doing it this is why it is known as well-structured costing system. So, it is a time driven ABC costing means as and when the activities keep on going the costing is Bill calculated that each point the costing is calculated here the cost drivers at each point are given and as in when the

process keeps on going from left to right the calculated the costly estimated accordingly. So, this is ABC.

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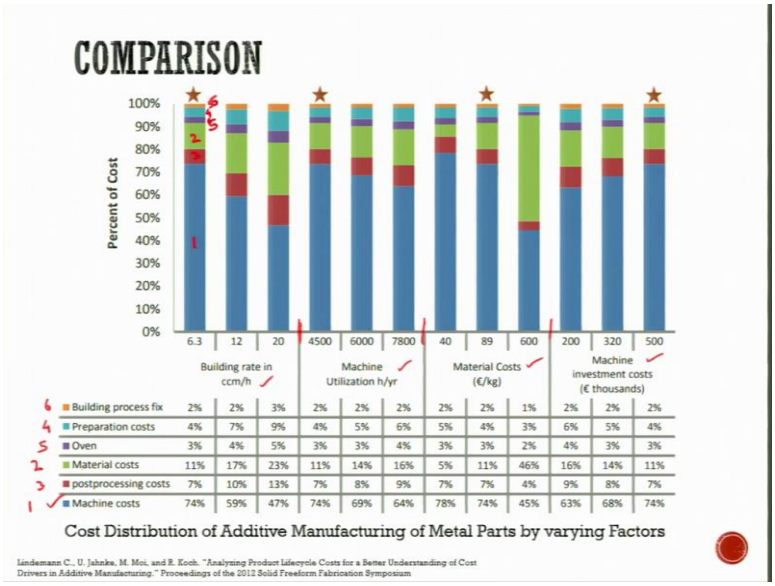

This is the comparison between the costing where you can see the blue color is the machine cost the maximum cost component in the percentages if you see here for the build rate, for the machine utilization, for the material cost and for the machine investment cost which is given by study by Lindeman catol in 2012 you could see the maximum component is machine cost then comes the costing for the materials here as the second part this is 1 this is 2 I am just editing it or marking it down as per the contribution or as per their percentages in the system first is the blue, second is the green, third is this maroon, then comes the light blue as fourth then we have 5 and 6 orange and purple I think the sixth should be orange, 5 should be this purple.

So, what are these? So, first one is machine cost, second one is the material cost, third one is my post processing cost then I get the fourth that is the light blue that is the preparation cost preparation means preparation of the system preparation of the build preparation of the machine preparation of the materials. So, all these different costs are taken here then we have the oven the electricity and everything else in it the building process fix finally when we try to do.

So, that becomes the sixth component. So, this is how the cost is distribution in the percentages if we try to see definitely it could be seen here that the machine cost is a maximum part because the machine is expensive and other materials are consumables but distributed towards the whole life cycle of the components which are produced using this

printer for instance if it produces 10000 of the components. So, it reduces to the minimum in the overall.

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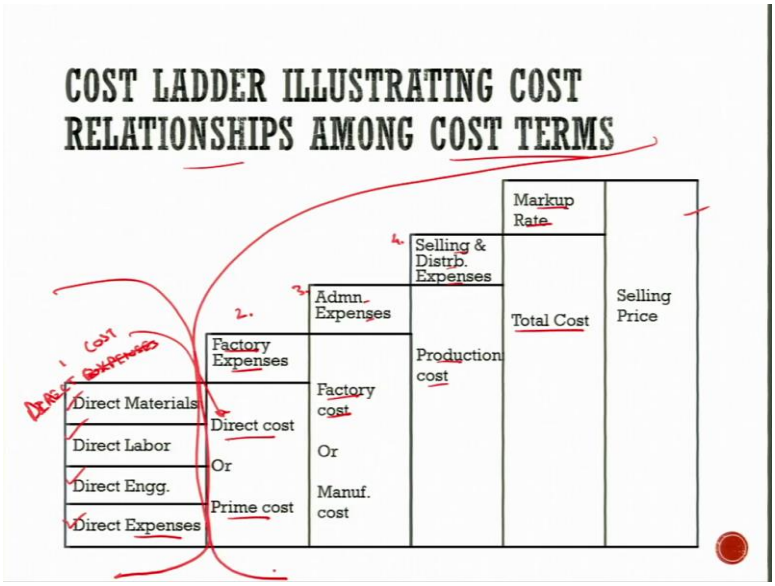

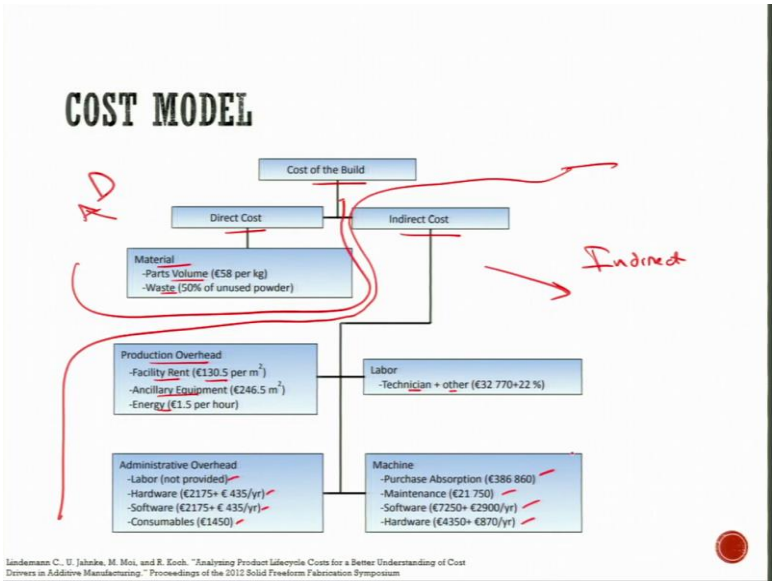

So, to see the cost of the build we have the direct cost and indirect cost the direct cost which was mentioned previously as well the material cost that is the pot volume which is given in the specific study there is 58 euro per kg the waste is 50 percent of the unused powder. The production overhead which is the indirect cost this is the only direct cost that we have, it is the first part in this, this is the direct cost rest all are the indirect in a way. So, just all the indirect are here, these are indirect.

So, this is direct in which the overhead costs are there labor cost is there over a cost you can see the facility rent it is mentioned for in this study that 130 Euros per meter scale this is a

facility rent here. Then ancillary equipment is costing 246 Euros per meter square energy consumption it is 1.5 users per hour for the labor the technician and the other the rate is given 32 thousand or 33 thousand users plus 22 percent maybe that is HRA or something.

Then administrative overheads that is labor it is not provided here the data was not provided the hardware computers etc in administration the software like Windows or certain other small softwares Microsoft Office or small other softwares which are there the consumables in administration all those costs are mentioned here then indirect cost itself the machine purchase absorption system, the maintenance of the machines, the softwares which are there in the machine for example, Iger software other software updates sometimes have to be purchased those are there small other hardwares that is the small units for the machine which are to be produced for example, the platform, the nozzle head etcetera those are all involved in the indirect costing.

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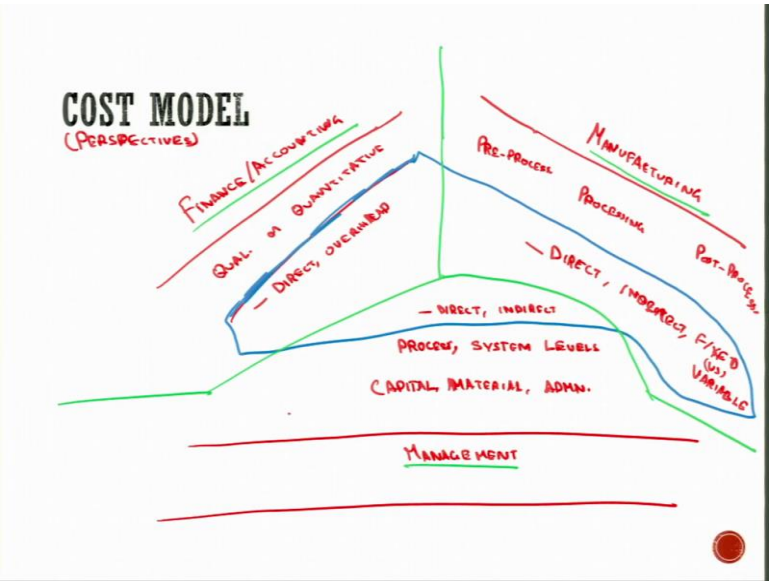

So, this is how the cost model looks like. So, cost could be looked from the different perspective by the different I would say levels of the hierarchy or different parts of the system parts of the system I would say different members of the system if I say the finance and accounting, finance or accounting person then we have the manufacturing person then I have the management they have different perspective for the cost I would say the perspectives.

So, what finance and accounting would say like in ABC costing it would say it has to be method based it could be qualitative or quantitative later it would say it the qualitative quantitative because whatever it is, it has to be concluded using parametric analogy or intuitive the estimating has to happen with all these ways but finally resolve to the direct

comma indirect or overhead etcetera courses. Then manufacturing person would say that the cost because we all I am manufacturing it one perspective it changes the cost model could be based upon the… I would say processing that is the building or the printing.

Then we have pre-processing then we have the post-processing. Here also finally pre-processing, post-processing the process oriented cost would again lead to the direct and indirect or the overhead I would say direct cost they would call it direct, indirect, fixed cost, it is the investment cost or so and variable cost, fixed or variable, fixed versus variable management would say we will calculate the cost based upon the capital that is investment.

Then they would say material, that is procured then administrative costs, here this could be they would say it could be at processed level for the specific process then certain processes being combined makes a small manufacturing unit, then small units being combined makes a system, these levels are there, but still they would again come to the finally direct in the processes or indirect in the processes, whatever we do you can see at the inner level,, we have to break down the cost into the direct and indirect.

In the outer envelope you see different people have different perspectives, there is a clear difference between these lines but finally we reach to a single point here. So, they are different, whatever we do, we need to understand the expenses, direct and indirect and those are to be divided into pre-processing these different kinds of models, we will try to see in the next lectures in the costing in a metal rate manufacturing thank you.