Metal Additive Manufacturing
Dr. J. Ramkumar and Dr. Amandeep Singh.
Department of Mechanical Engineering and Design, IIT Kanpur
Lecture 47:
Industry 4.0 and MAM

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Hello everyone, welcome to the last lecture of the course, metal additive manufacturing, I will have to summarize the course in the end of this lecture as well. So, this lecture is on Industry 4.0 and the metal additive manufacturing. I would love to introduce the concept of Industry 4.0, the 4 revolutions which the world has been through.

Now, Industry 4.0 design principles, smart manufacturing, harmonizing the TRL, that is Technology Readiness Level, and Industry 4.0 future with additive manufacturing, some example companies who are employing the concepts of the Industry 4.0.

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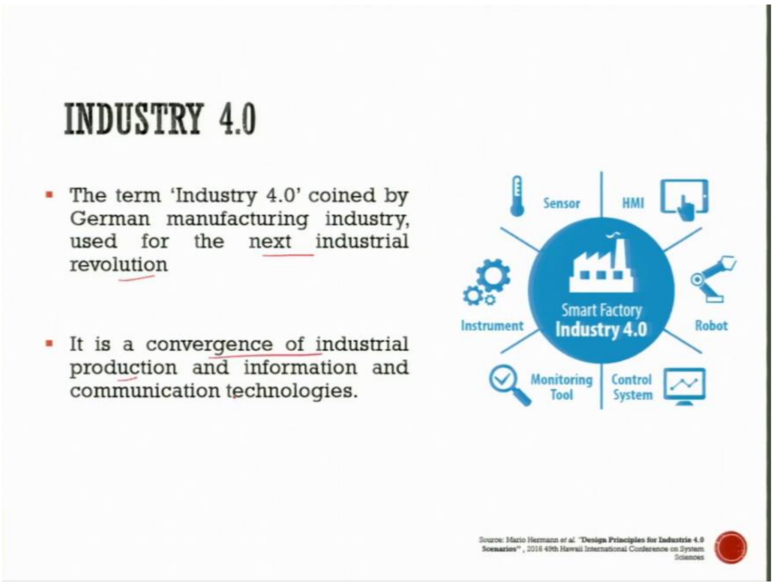

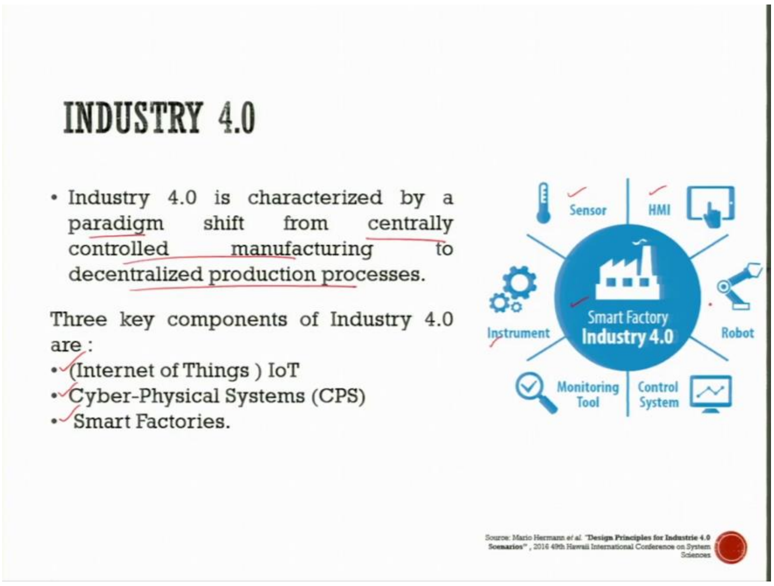

The term Industry 4.0 coined by German manufacturing industry used for the next Industrial Revolution. It is a convergence of industrial production and information and communication Technologies. So, what is Industry 4.0? We will try to discuss it a little. Industry 4.0 is characterized by a paradigm shift from centrally controlled manufacturing to decentralized production. Decentralized means remote production or smart production or having a virtual Factory. Using certain tools we have the internet of things as one of the entities or elements, major elements, then we have cyber physical systems which helps the internet of things, that is the components or the sensors to connect with the factory.

Then we have the smart factories, the smart Factory it is connected by a sensors HMI instruments and robots which are monitored by a monitoring tool and a control system. What is this fourth Revolution? We have been through the different revolutions which we will try to see here in the history.

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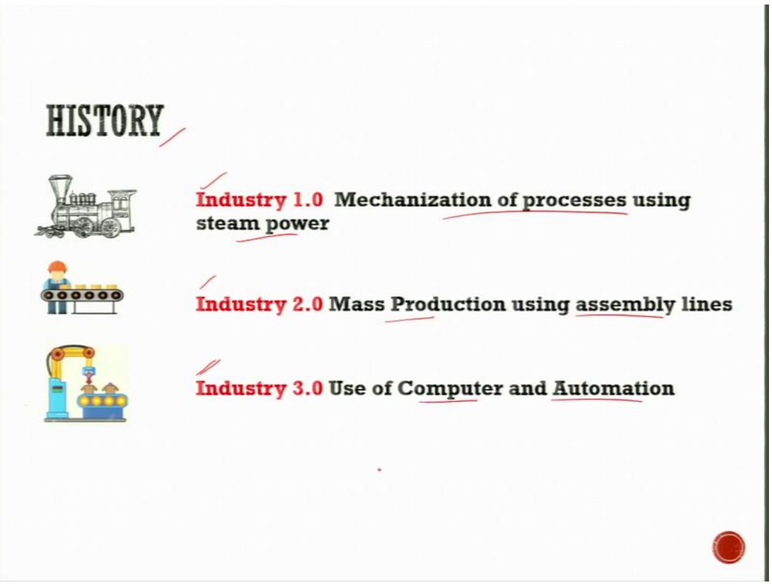

Industry 1.0, Industry 2.0, Industry 3.0, when the steam was developed first, when the steam was explored as one of the sources to have the mechanical advantage from it, that was Industry 1.0 when mechanization of processes using steam power was there. Then later in the time of the Edison, Tesla, electrical power was brought into use, then mass production using assembly lines was possible.

Industry 3.0 this is the time that the people of my age have witnessed where the computer and automation were there. Since 1990s, the computer came as a tool which can help to compute faster, later the space constraint which was there earlier or only a 2 MB computer was loaded in a full truck. So, now we can have multiple or thousands of GBs or TBs of data in a small pen drive size gadget.

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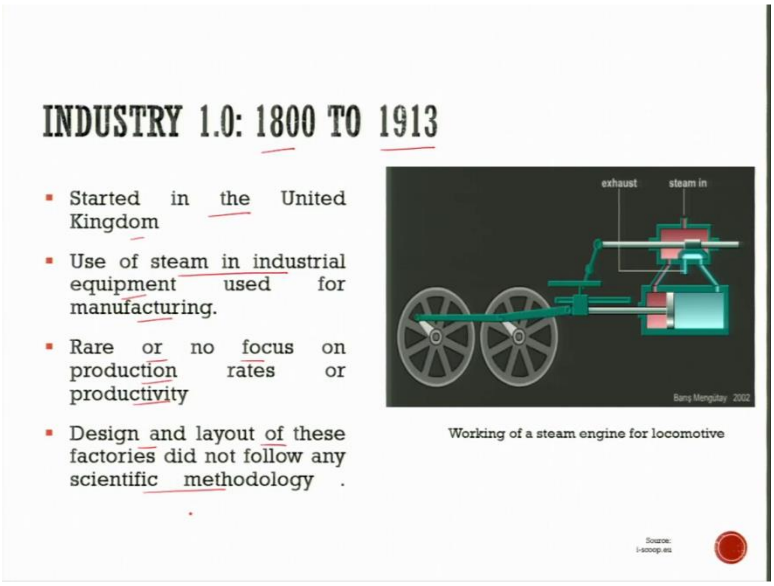

So, now Industry 1.0 was from 1800 to 1913, we started in United Kingdom. Use of steam in industrial equipment was used in manufacturing. Rare or no focus on production rates and productivity was there because only the use of some mechanized system, some external power source that is steam source was only explored. Design and layout of these factories did not follow any scientific methodology, because whatsoever was coming, nothing was laid out and it was only being used.

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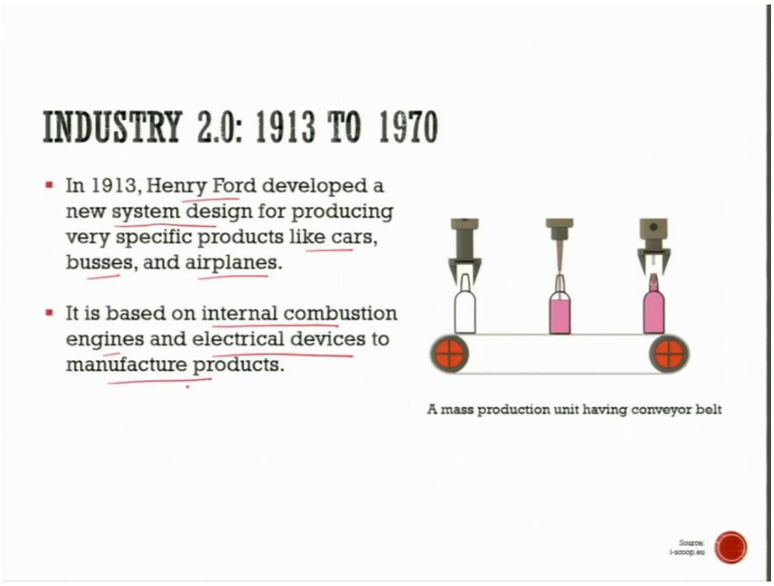

So, from 1913 onwards, when the automation of the systems was possible, then Henry Ford first developed a new system designed for producing very specific products like cars, buses, airplanes, which were put in the clear lines. This was some system which was based upon internal combustion engines, and electrical devices, that it was used to manufacture the products.

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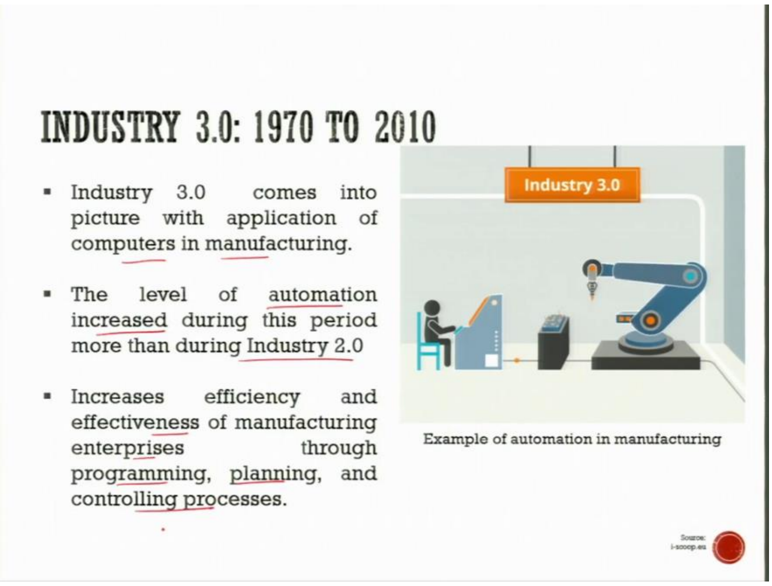

Then Industry 3.0, in which the Computer Applications came into manufacturing and the person was able to work using CNC, computer network control, before even that the numerical control systems, the level of automation increased during this period more than the Industry 2.0. Increase efficiency and effectiveness of manufacturing enterprises and through programming, planning, controlling techniques, these came with the multiple management techniques like material requirement planning, manufacturing resource planning, then we have enterprise resource planning, everything now is now being converted into digitalization of the manufacturing, what we call generally is as product life cycle management of the industry. In the product life cycle management, there is a sustainable product cycle management as well. So, this is what Industry 4.0 is not connected to.

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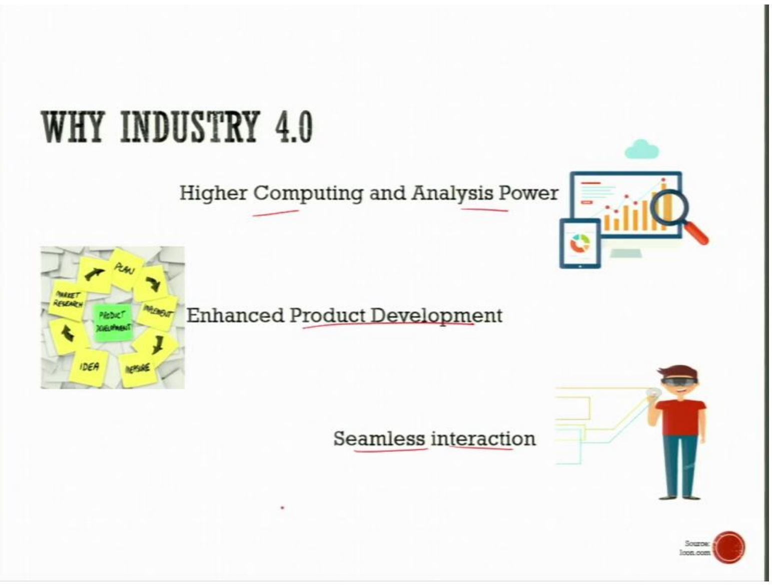

Here, higher computing and analysis power is there, which means the rapid increase in data volumes, cloud storage, computing power, network connectivity, this has all enabled analysis of the operational data that was previously almost impossible. Then we have enhanced product development, by product development I wish to say here is that the advancement in the analytics capabilities.

The product analysis required a successful and strong and solid analysis, the higher would-be quality of the product analysis or product development or design, the better would be the quality of the end product as well. Now, we have seamless interaction, that means we can connect through various elements, various sources, that is the human and machine interactions are not possible, these include the development of AR, that is augmented reality, mixed reality systems which make use of the touch interfaces, and other hand phase operating system as well.

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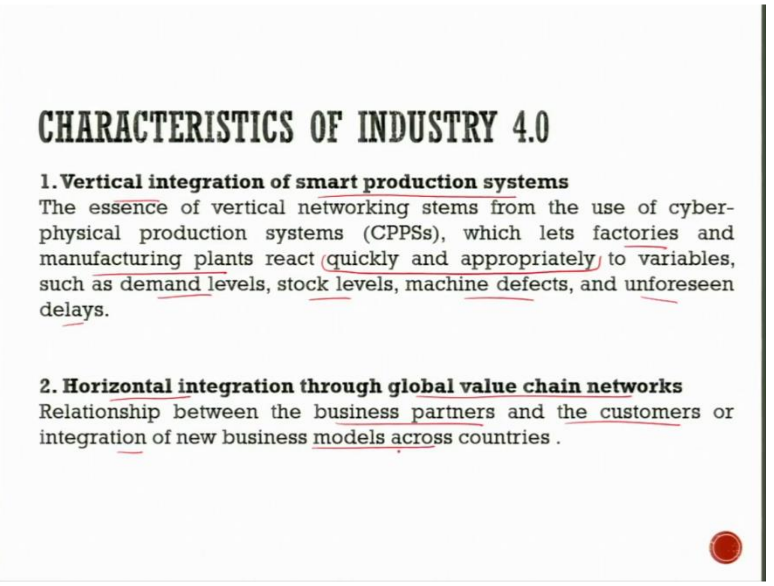

To lay down the characteristics of Industry 4.0, number 1, vertical integration of smart production systems, the essence of vertical networking stems from the use of cyber physical production systems which lets factories, and manufacturing plants react quickly and appropriately to the variables such as demand levels, stock levels, machine defects, and unforeseen delays, this means the vertical integration is possible. Earlier to pass the document from one place to another it took time, these days we have WhatsApp, we have the internet, the internet, the computer that I showed you in the demonstration in the laboratory, that was cloud control being in some other city itself, I can give a command and set the printer, right.

So, this was all taken as vertical integration only, and the flaws in the machine everything could be seen there. Then horizontal integration is also possible through global value chain networks. That is the relationship between the business partners, and the customers or integration of new business models across the countries is also possible.

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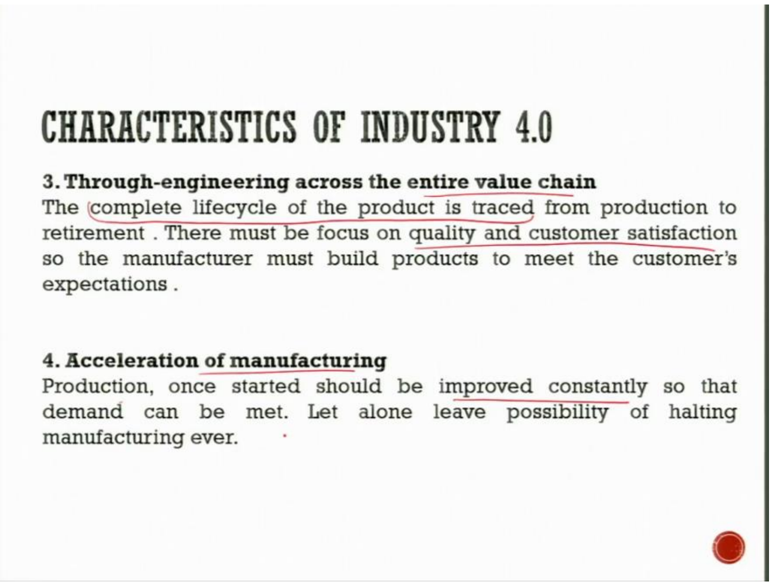

Then through engineering across the entire value chain, the complete life cycle of product is stressed. From production to the retirement, they must be focused on quality and customer satisfaction, so the manufacturer must build products to meet the customers' expectations.

Acceleration of manufacturing production once started should be improved constantly, so that the demand can be met, let alone the possibility of halting the manufacturing. So, this is possible through Industry 4.0 principles, because we have sensors, we have the online monitoring systems in CT control, and monitoring everything is possible.

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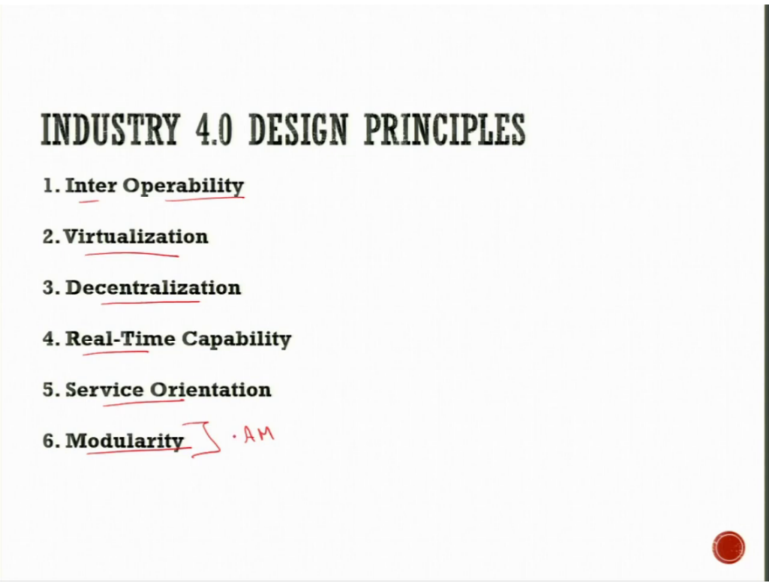

Now, to elaborate these design principles, number first is inter-operability that is this requires an entire environment with fluid interaction, that is the flexible or the smooth interaction and flexible collaboration between all the components. Then virtualization, virtualization means monitoring of actual processes and machinery that takes place in a physical word and returning sensor data. So, this will then be linked to a virtual model or a model which are created in a simulated model.

Then decentralization, decentralization means it supports the different systems within a smart factory to make decisions autonomously. That is decisions were taken by itself by the machines without deviating from the path toward the single or ultimate organization goal. The system is set in such a way, then the organization or the upper level hierarchy set the system that the changes is smaller there, the machine itself, the machine or the operator itself can take the decisions there, based upon the laid criteria, this is decentralization.

Then real time capability, real-time capability means this requires the production process to collect the data, and feedback and monitor the processes in their real time, in the achieved real time, that is the live data monitoring or reading is possible now. Service orientation, service orientation that is the internet of things creates potential services that others can consume, therefore internal and external services are both possible, and these code through the requirement of the smart factories. Which is why the internet of things and internet of service is should be important component of Industry 4.0.

Then modularity, this is where our additive manufacturing comes into play, that is we are can have a, we can propose or we can put a flexible and modular designs. So, flexibility is an important principle in Industry 4.0, so smart factories can easily adapt to the changing circumstances. So, that is why the system is developed in modules, where our requirement is there, the change could be made the system could be or the component could be replaced, expanded, improved, worked upon with minimum disruption or disturbance to the other products or the production processes. Now, building blocks of Industry 4.0 would be big data and analytics.

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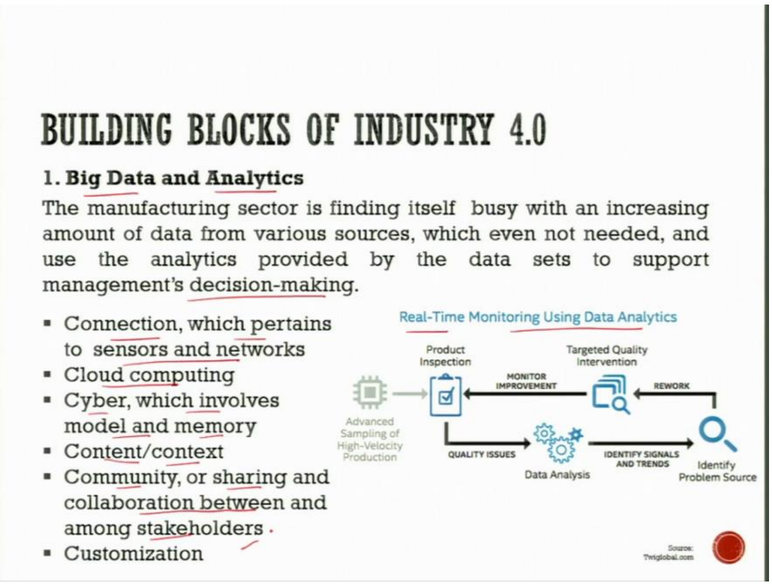

The manufacturing sector is finding itself busy with an increasing amount of data from various sources, which even not needed and use the analytics provided by the data sets to support management decisions making. So, big data means a large amount of data, each machine will be producing data each second maybe, each millisecond. Then each machine each element of the machine, each operator this data keeps on getting accumulated makes a bigger data to how to handle the data, how to envelop the data into one, there is something known as data envelopment analysis, there is something known as big data analytics in which various tools could be used.

So, these different real-time monitoring's using data analytics is possible through big data analytics, which is the part of the Industry 4.0. The connection which pertains to sensors and networks, the cloud computing, the cyber which involves the model and memory, the content and context of the system, community or sharing and collaboration between the stakeholders, then customization, this all is having a lot amount of data which is big amount and that is known as the big data.

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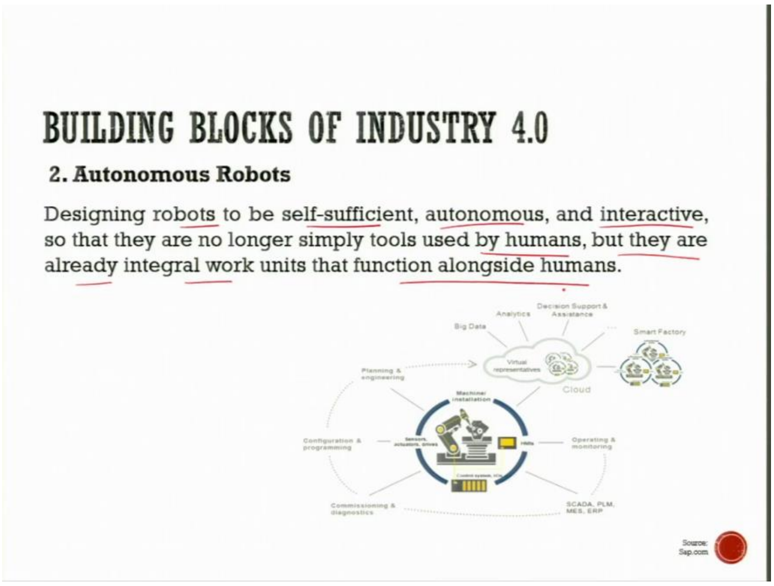

Then autonomous robots, the robots in the Industry 4.0 scenario are if not fully, but partially or largely autonomous, that is the take the decision by themselves, whether the piece is defective, they do not use it, if the piece is usable to try to only select only that. So, based upon the techniques, the different techniques, the contact and non-contact techniques that we have discussed in the non-destructive testing that we have discussed in reverse engineering system as well.

The robots can visualize, they can touch, they can have certain small control system, and try to be autonomous. The designing robots to be self-sufficient, autonomous, and interactive, so that they are no longer simply tools used by humans, but they are already integral work units that function alongside humans. So, these days even there is a concept of cobot, a robot working in collaboration with human, whatever. So, for example there is a large force required to do something with hand, I develop a cobot, whatever force or whatever movement I do, the cobot will do the similar.

So, similar for example for a dental surgery is also, people have now started using cobot, the cobot will try to only work as per the direction, as per the movements given by the dentist itself. So, there is this Concepts. So, these are the also concepts which are now the part of the recent Technologies.

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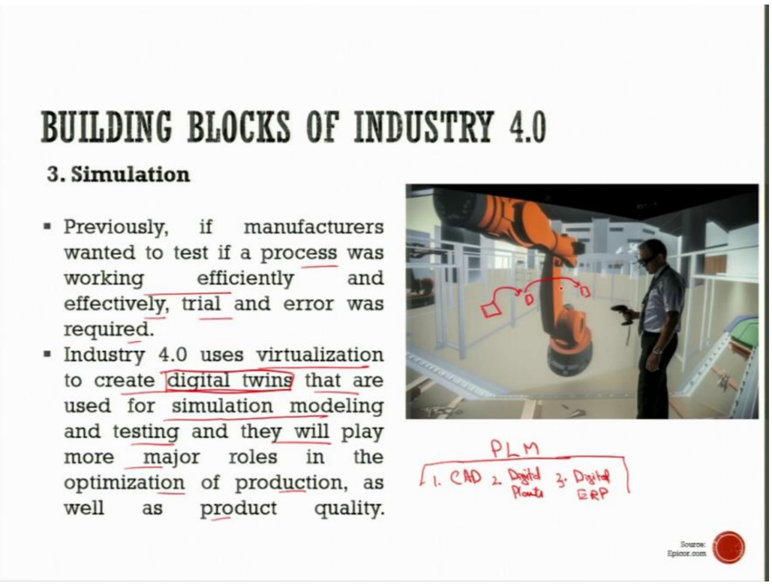

Simulation means imitation of reality, the previously if manufacturers wanted to test a process it working efficiently and effectively, trial and error was required, Industry 4.0 uses virtualization to create digital twins. Digital twins mean there is a physical system, this we can create a digital system very similar to that. For example, if there is a motor, if I try to run this motor in an overloaded condition for the extended number of hours, at what point a motor gets heated, I create a digital system as well that after 5 hours of the overloaded condition, the motor will start heating also or this digital model would also show the heated part of the motor. So, digital and the physical system there is. So, this makes the digital twins.

This is virtualization of the system. So, these are used for simulation modelling and testing and they will play more major roles in the optimization of the production. So, there is something on also that I just mentioned, product life cycle management, PLM. In this also, first is the design that is the CAD models.

Then we have digital plants, that is also a second portion of it. Then, we have the digital enterprises resource planning. So, this is product life cycle management contents in general. So, digital plants, here we can see a digital plant, digital plant in a way the machines could be kept here at vertical places, how the material flows from one machine to another, or the robots will pick the machine heads, this all is possible and simulation is not totally limited to the static or the dynamic simulations that we do for the product or for the component, we can even move to the system development, that is the manufacturing or factory development.

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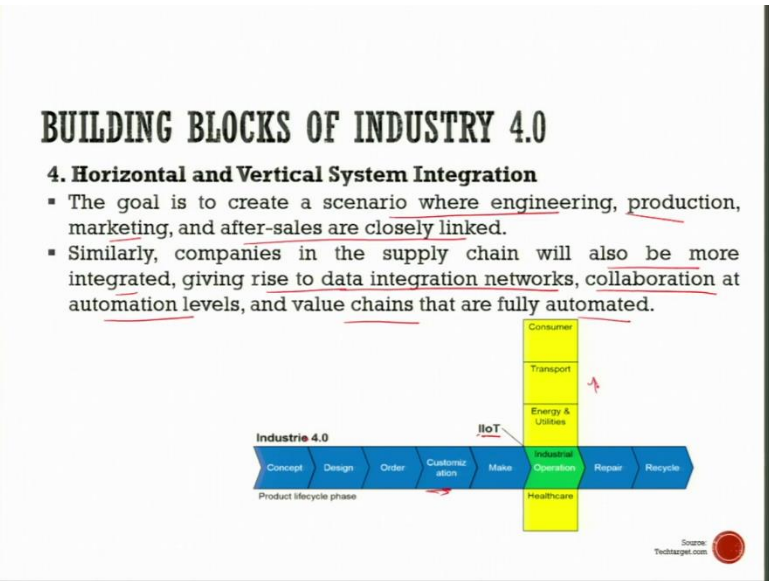

Now, horizontal and vertical integration which I just discussed here. The goal is to create scenario where engineering, production, marketing, and after sales are closely linked. Similarly, companies in the supply chain will also be more integrated giving rise to data integration networks. Collaboration at automation level and value chains that are fully automated. Industry 4.0 is there, so in which we have the horizontal integration, also we have the vertical integration, we have Internet of things and IIoT, that is Industrial Internet of Things. So, that helps us to make the operations, operations can have horizontal and the vertical interaction as well.

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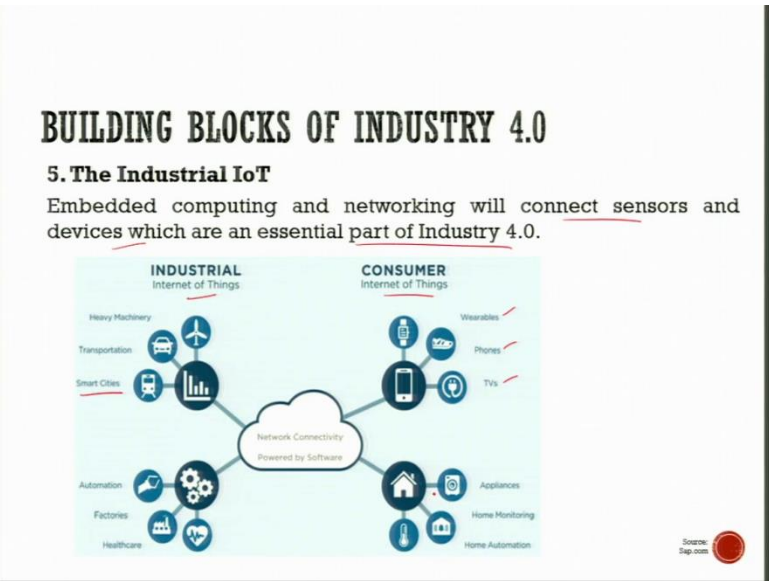

The industrial IoT, IIoT the embedded Computing and networking will connect sensors and devices which are an essential part of Industry 4.0. And there is still enough to things and consume Internet of Things, together help us to bring the 4.0 reach maximum, we can have Smart cities, we can have the consumers having the variables, phones, TVs at homes, where you can monitor and see the systems, and they can monitor, their health they can monitor, their businesses they can monitor their homely activities, all these things could be used.

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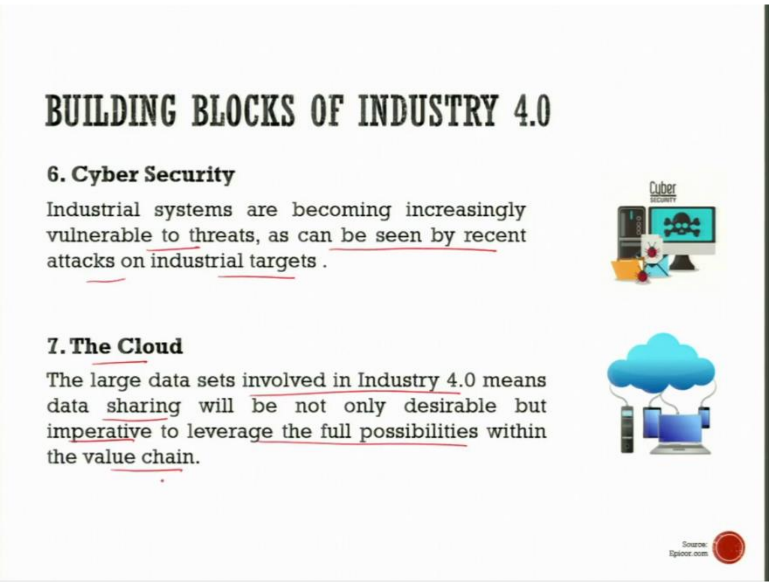

Cyber security, the Industrial Systems are becoming increasingly vulnerable to threats as can be seen by the recent attacks on Industrial targets. So, to install these systems is not only for automation, just to keep ones and safe also some has to understand the system, for example, if I am using a computer, I need to understand what are the virus threats to my windows or to my other programs and which I am using. So, for that itself, the cyber security systems are to be understood.

The cloud, the data sets which are involved Industry 4.0 means data sharing will not only desirable, but imperative this is imperative to leverage the full possibilities within the value chain. So, this data can be stored in Cloud, we can only have access to the cloud and try to collect the data, use the data, when and wherever necessary.

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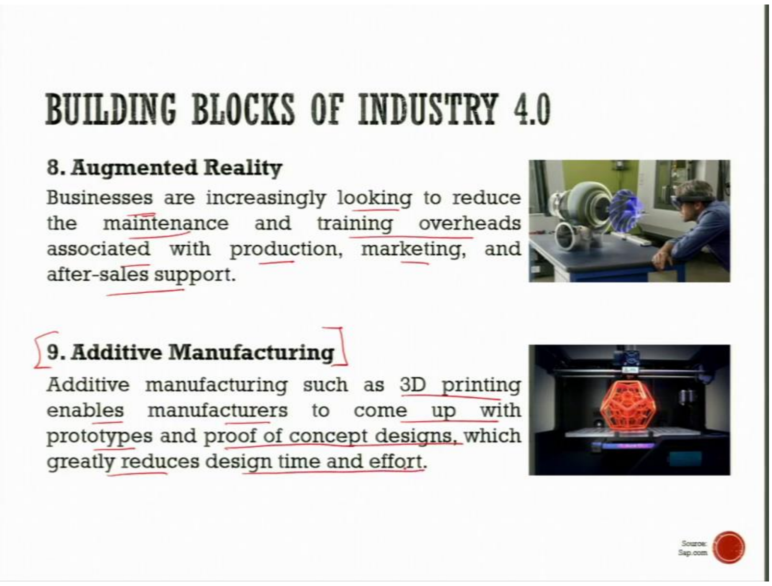

Augmented reality, augmented reality is close to what I just discussed about the digital twins. So, virtual reality you all understand is something a factory or a machine in a virtual environment, where completely virtual enrolment is there. Augmented would be the virtual environment augmented with the human interaction. Mixed realities also there where some parties virtual and some part is completely human. So, augmented reality where businesses are increasingly looking to reduce the maintenance and training overheads, associated with production, marketing and after sales support.

Next comes our core thing additive manufacturing, additive manufacturing such as 3D printing enables manufacturers to come up with prototypes and proof of Concept Designs, which greatly reduces design time and effort, this is what we are trying to focus in this lecture, and how is this possible.

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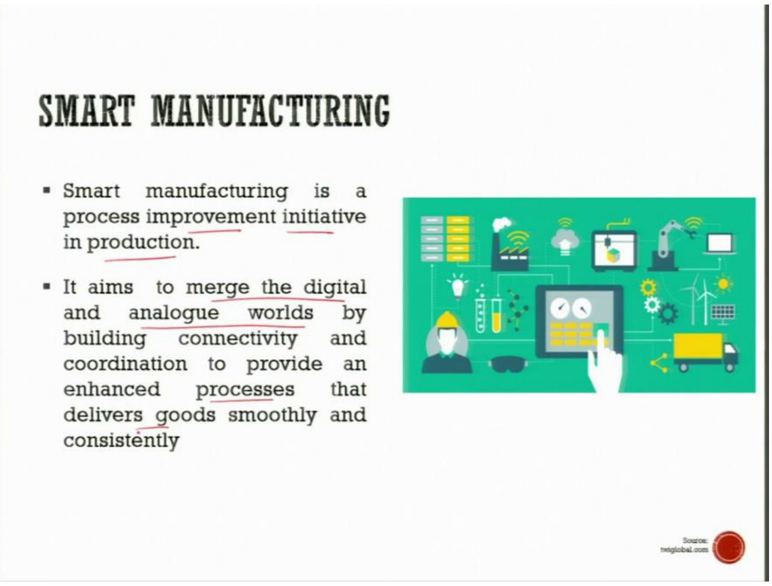

Let me try to see what is a smart Manufacturing? In a smart manufacturing. It is a process of improvement initiative in production it aims to merge the digital and analogue worlds by building connectivity and coordination to provide enhanced processes that deliver goods smoothly and consistently.

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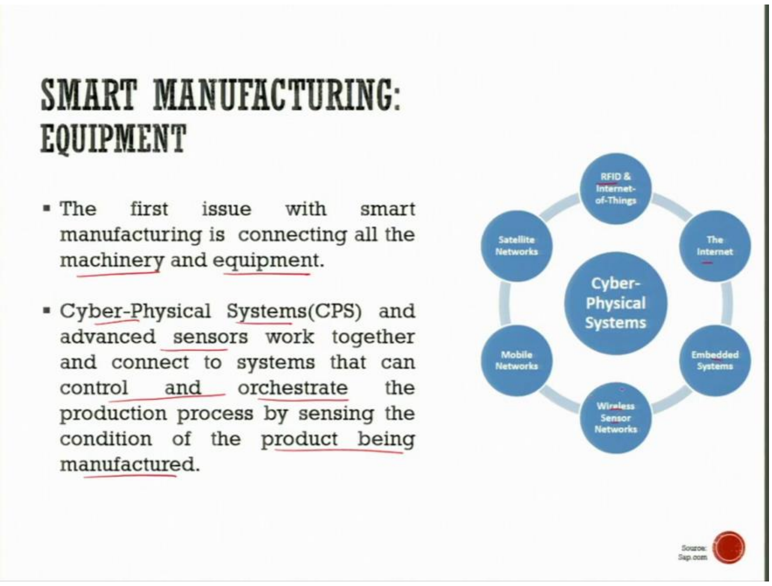

So, what systems are required in a smart factory? The first issue with smart factory or smart manufacturing is connected about machinery and equipment. A cyber physical system an advanced sensors work together and connects to systems that can control and orchestrate the production process by sensing the condition of the product being manufactured. So, this is how a smart factory, in general works in a cyber physical system, we have satellite impact networks, we have the internet of things in which RFID is one of the tools, we can have QR and some other systems as well the internet, the embedded systems, the wireless sensors, these are all the cyber physical systems which are the part or the equipment in the smart manufacturing system.

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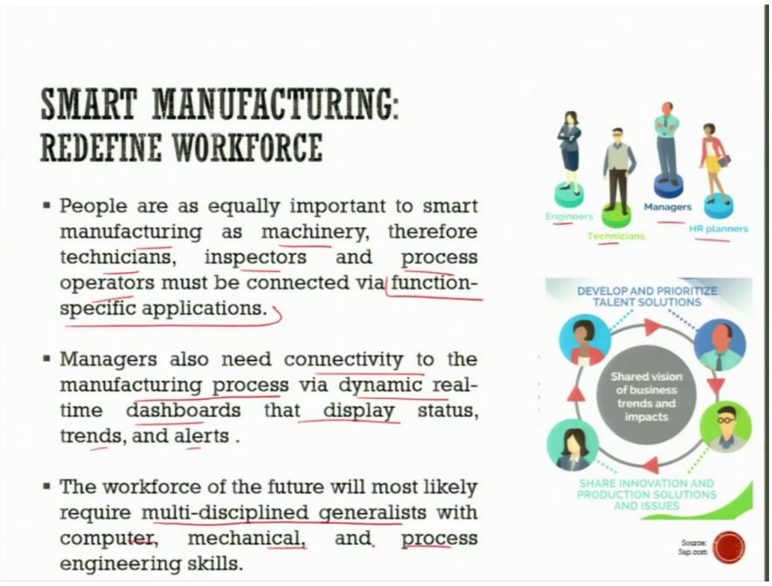

So, we redefine the workforce, workforce does not only means that we need to have separate Engineers, technician managers, or HR planners, they are to be connected each one should be able to understand the other person's work, because smartly working on a single platform, if suppose we are using a project management software itself or project management to a tool itself, like Trello, like Jira, like maybe Google suit or so, there also where to put data, who is going to access the data, in this case we also need to redefine what workforce or what kind of training our employees need to have.

People are as equally important to smart manufacturing as machinery, therefore technicians, inspectors and process operators must be connected via function specific applications. Managers also need connectivity to the manufacturing process, while dynamic real-time dashboards that display status trends and alerts. The workforce of the future will most likely require multi-disciplined generalists, with computer, mechanical and process engineering skills.

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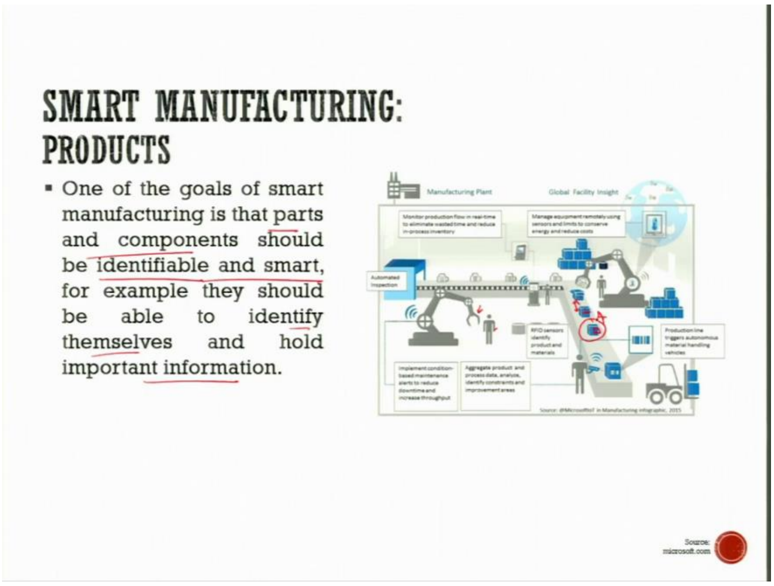

The products in smart manufacturing one of the goals for smart manufacturing system is that the parts and components should be identifiable and smart. For example, they should be able to identify themselves and hold important information. For this case, sometimes the components which are there, again we can connect the components of the boxes which are the cartons, which are assembled or which are shown in this assembly nine, we can mark a small QR here or we can also put a RFID code here or we can see, whether what is the distance between these components the colours could be more different.

So, all these things the products should be able to identify themselves, this is how we try to automate the system, either we try to put the sensors here in the robot, robotic arm or we try to put it there with the augmented reality systems with humans, some sensors or some gadgets they might carry in the hands or they might tie something on their wrist a band or so or we can also put something on the components or the systems itself on the boxes. So, a manufacturing plant a global facility inside is something like this.

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What makes Industry 4.0 a practical or realizable or implementable system? Network systems provide connectivity for localized decentralization information processing. Progressive mini utilization allows for small auto ID for customized product manufacturing creates unique identification and links to the virtual world. Intelligent field devices using software that allows for the global Dynamic distribution of functionality, this is an integral part of the system integration. Mobile device management also makes the man machine interfaces for the intuitive operation of complex systems without special training.

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Now, there are major challenges that the time and cost for further increasing and the overall Readiness level of the fusion energy that is system developing the system here which is we say the different systems are there, cyber physical system internet of things, editing manufacturing, human, machine, robots all those are to be fused together, that is why we need the overall readiness level that at what point are we now.

Testing materials under extreme environment, data collection, analysis, and assessment, new design of components. So, Industry 4.0 is on its way as of now trend to use automation and data exchange technologies that is cyber physical systems, internet of things, cloud computing, cognitive computing to perform industry activities, nuclear sector has not yet caught up with Industry 4.0 this is an important mention. So, we started from mechanization Industry 1.0 to electrification Industry 2.0 to computerization, the third revolution, now digitalization as the fourth revolution.

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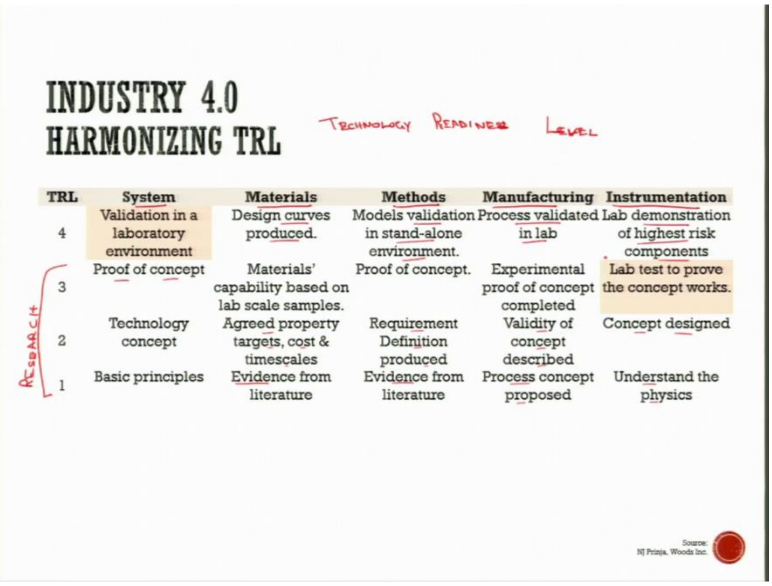

TRL	System	Materials	Methods	Manufacturing	Instrumentation
4	Validation in a laboratory environment	Design curves produced.	Models validation in stand-alone environment.	Process validated in lab	Lab demonstration of highest risk components
3	Proof of concept	Materials' capability based on lab scale samples.	Proof of concept.	Experimental proof of concept completed	Lab test to prove the concept works.
2	Technology concept	Agreed property targets, cost & timescales	Requirement Definition produced	Validity of concept described	Concept designed
1	Basic principles	Evidence from literature	Evidence from literature	Process concept proposed	Understand the physics

Next, I think I would like to also discuss the TRL, the technology Readiness level, and we will try to see how additive manufacturing has helped to lower the TRL level requirement in order to take the product to the really marketable or sellable position. So, this is TRL, that is technology, by technology we mean the process, the method, the machinery, the equipment, the techniques, or the software, anything that could be technology, and its readiness. Readiness means how mature the technology is, is the technology really capable of doing something in real world or are we only in a redesign phase or so, that we will see in this table and the level, technology readiness level.

Level would be actually the real maturity, that is being used or being developed that level could be set in these nine-point scales. So, point 1 to 4 is the basic principles of the technology, point 1 is the basic principles in which we can see this is a technology readiness level, template for the practical use, how to or where do the technology lies. So, it could be the whole system what is the level from the material viewpoint, from the methods being in the technology, from the manufacturing and in the instrumentation.

So, first level is the basic principle, basic principle means the fundamental attributes that have been established, in which the evidence from the literature is taken, the evidence from literature is taken in the methods, process concepts and proposal manufacturing, understanding the physics is there in instrumentation, so this is the basic principle. Next comes, the technology concept and what is invention and what is research or what practical application could be created later as well as the phenomena to be investigated, the knowledge that is to be learned, knowledge to be integrated, in this we try to see whether agreed property targets, cost and time scales are there in materials, in method we say requirement definition produced, then validity of concepts and describe, concepts designed in instrumentation.

Then in the third level, we have the proof of concept, proof of concept means at least a theoretical illustration of how the invention might function. We have at least a small design, maybe you know design the draft ready. So, in this case we only call it this is only research I would put it here, this is only the research about the technology. Then comes the validation in a laboratory environment when we have the first prototype ready. So, this is the technology development level 4 which we call it is a bench scale level, that is the product starts taking the shape in the laboratory or in the research facility.

So, we have in the case of material design curves produced, we have small monographs maybe. So, methods would be validation of a standalone environment specific environment, for example it is not a scenario analysis, it is only the sensitivity analysis keeping everything else constant, my product would behave or would have this much of the deformation, when I try to see the tensile strength. So, something like that everything else is kept constant it is a standalone environment. Then manufacturing process is validated in the lab, laboratory demonstration of highest risk components that is what is the highest risk. So, those things are taken here, this is the level 4.

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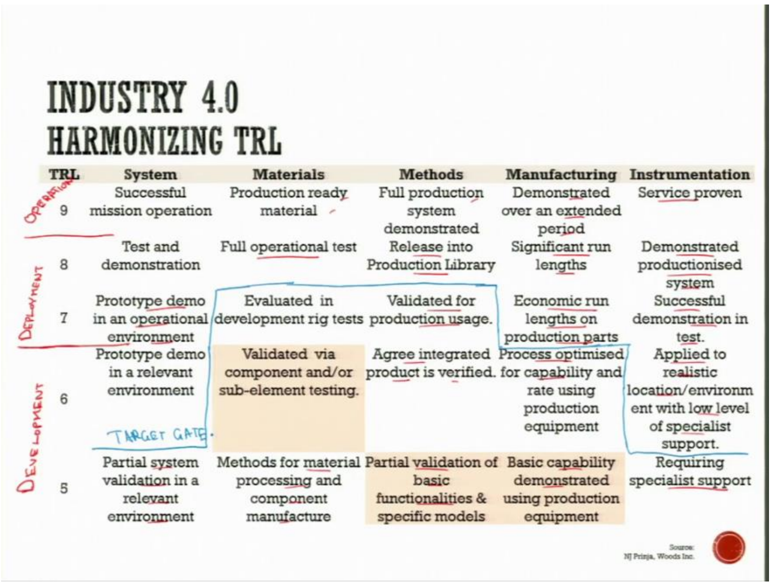

Then we have the level 5, in which partial system validation in a relevant environment is there, which means the pilot scale or the product which is now is from maybe a medium to little high-fidelity level. The fidelity level changes, at the level 4 it was only the low level, I would say low fidelity level only. So, in these methods for material processing, component, manufacturer… in the material, in the methods, we have partial validation of basic functionalities, in the manufacturing the basis capabilities are demonstrating production equipment, and requiring specialist support is there in the instrumentation.

Then we come to the level 6, which is a large scale that is the prototype, in a relevant environment. So, this becomes the next level. So, till level 6 where the large scale component is now available that is a testing at the close or full scale dimension is not possible, the equipment will still be in the process of modification, because certain design or feedback might come from the customer who are using it the customer, we are trying to use if. When I say customer, it does not mean the final customer, it is on the internal customer or the laboratory people who are trying to test or who are trying to see the level of the prototype that we have developed.

So, they agree on the integrated product and is verified the process is optimized for capability in manufacturing. In instrumentation this is applied to realistic location environment with low level of specialist support. So, in this case, till the 0.6 we can say development has happened, right. Now comes, the level 7, generally when patents are file though starts from design pattern is only listed at level 3. From the prototype level, like generally the pattern start from level 4, if it is level 5, that is the prototype now demo could be given in a personal environment.

Why I am trying to talk about all this is? I will try to connect this to the additive manufacturing that while having additive manufacturing systems possible now, the TRL level from where we can take the product to the market is now brought to the lower level. Now, in the 7th level of the TRL, the technology is now ready to be passively commissioned, that is using in actives similar to those anticipated during the operations, the work testing or the field trials could be taken. So, full throughput is not anticipated here, it is validated through the Productions uses the methods the economic run lens at production plants is taken for the manufacturing and instrumentation, successful demonstration in the test is taken. So, here I have started my deployment. So, this deployment continues till level 8, where the test and demonstration is now taken at an active commissioning level, that is actively the technology is being commissioned, it is fully operational test, it is the release into the production library the methods, significant long runs for the full-time production it is now taken, and the instrumentation is demonstrated productionized system.

So, this is deployment, finally, we get the operations or the final use, actual use, I would put it as operation at that technology level, or TRL 9, at TRL 9 successful mission operation is there, that is operations are now ready, the technology is currently being used in an operational facility, the product is finally being used by the customers. So, successful mission is there, the material production ready materials, we have full production system, we have in the methods in manufacturing, we have demonstrated an extended period, and service is proven.

Now, the point is that, in general some levels of the technologies are there. For instance, if I have a technology in which I need to put the TRL level, the generally I would say that it is from the system viewpoint I am only at the partial system validation, that is I have come to my development, the prototype is ready but still it is not completely validated. However, the materials for the prototype are valid related to some extent that is I have evaluated and tested the material part of that and development rig tests are we have been taken.

Similarly, the methods have been tested. So, I am just putting some hypothesized system or hypothesized technology which I have in which the TRL level for at different functions would be something like this. For the methods of validated through production usage and even the materials and methods if those are validated permanent fraction level could even be lower, that means I do not have the economic runs yet, but the process is optimized for the capability, rates using the production equipment to some level.

And the instrumentation is still also not ready because the production system is yet not tested. So, instrumentation only requires still a little specialist knowledge, that instrumentation would only finally come, when the technology would be ready. And I am very sure, that the methods, the materials, the manufacturing system is there, then only I will understand what instruments are required finally there in the technology.

For example, this is the status of the technology, TRL level is this 5 starting from 5, because the prototype is now ready. In the absence of additive manufacturing, what used to be? We used to develop the prototypes using the conventional manufacturing systems only and we were not able to have the feel of the product.

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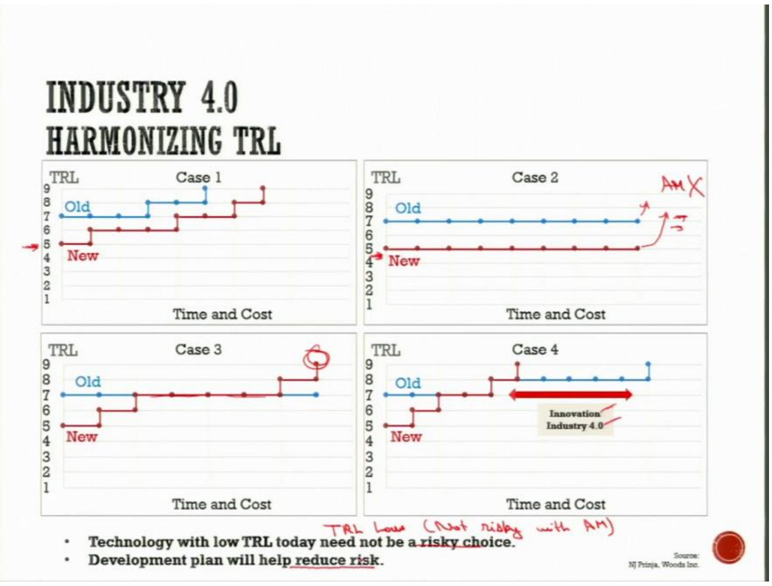

Now, let me have 2-3 cases here. Case 1, the old system let me say have a technology that starts from level 7, and the time in the course which is being invested is something like this. So, first case could be the technology could start from a level lower, because at level 7, I have completely tested the product, using editing manufacturing I have developed the product in a lesser amount of time or I in the beginning at a level 5 itself when I had the first prototype ready, I was able to develop some components of them. So, only 1 step lower than this or 2 step lower than this I am able to do that but the time taken is little higher.

Another case could be when the old system is still stuck and continuously and still with the long running times, I am not able to get any Improvement, but still here, using editing manufacturing you can have the system here, but we are not able to get up then this time is still kept here. So, another case 3, which is now the enhancement of case 2 using additive manufacturing or using something that helps us to understand the methods, the manufacturing better we can able to rise little higher level, and we can reach the target here the product reaches the customer.

Finally, this is the case in which innovation and Industry 4.0, if everything including the editing and fracturing those come here these points are actually known as the target gates. So, this is something that I showed you in the previous slide as well, this is my target gate.

That is at what target are we or from where are we trying to reach to which level. So, in this case, I could say here the technologies with lower TRL are not tested or not taken further because you can see in the case 2. So, the time and cost is being invested continuously but still the technologies are not able to mature do not able to go to the next level. So, that is why the technologies do not go here, we do not use or I would say in the case 2 the additive manufacturing is not used.

Now, the technologies with low TRL are no more much risky, I would say TRL low not risky with additive manufacturing or maybe also with the help of Industry 4.0 internet of things or so. So, this is what is the benefit of additive manufacturing or the role of additive Manufacturing in the overall scenario of the Industry 4.0. So, it is also mentioned here technology with load TRL today need not to be risky choice and development plan will help to reduce the risk, because we will have the product in the physical form in our hand, we can have the feed of the product maybe suppose if the final product is made up of in colon or. So, at least with PLA the first field or the size of the may be scaled down model of that we might have in our hand and we can call it a low fidelity product and we can see the actual shapes, holes movement of the different materials within that component.

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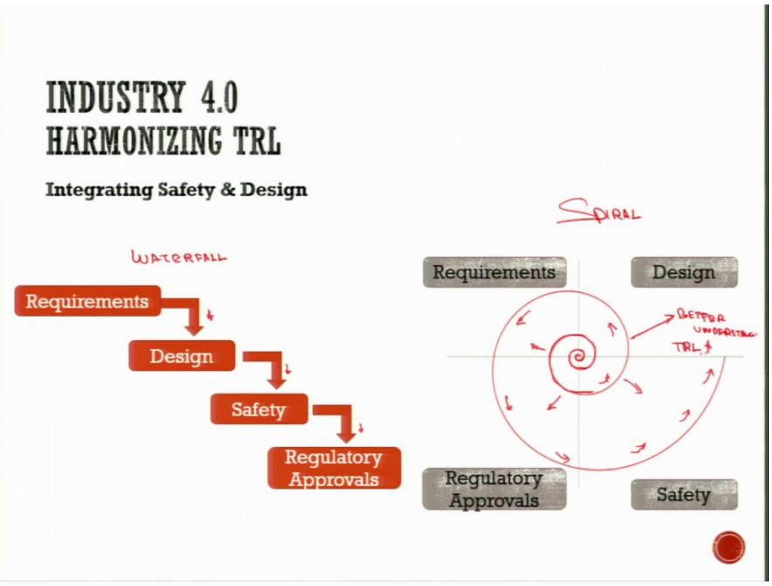

Now, what I am trying to say here is that, we are able to integrate this safety within the design, that means this was the previous system in which requirements were there, from the requirement design was made that develops us to help the system graph and everything then we have the regulatory improvements, this was a waterfall, that the way it keeps on coming it keeps on letting the things come to the ground and it keeps and gives us the final result here

Nowadays, it is not the waterfall it is now a spiral, but spirally means the design, requirement, regulatory, improvements keep on going hand in hand because we are able to see the design or change the design or change the product or present the product and the level of the design, level the requirement is key upon increasing as and when and keep on moving along this spiral, that is safety layout is also now quite high, this is how the system is keep on going with a very low level or lower understanding.

Here, the understanding level when I moved from the region in any of the directions, the understanding level is increasing. I would say better understanding the product or I would say TRL is higher.

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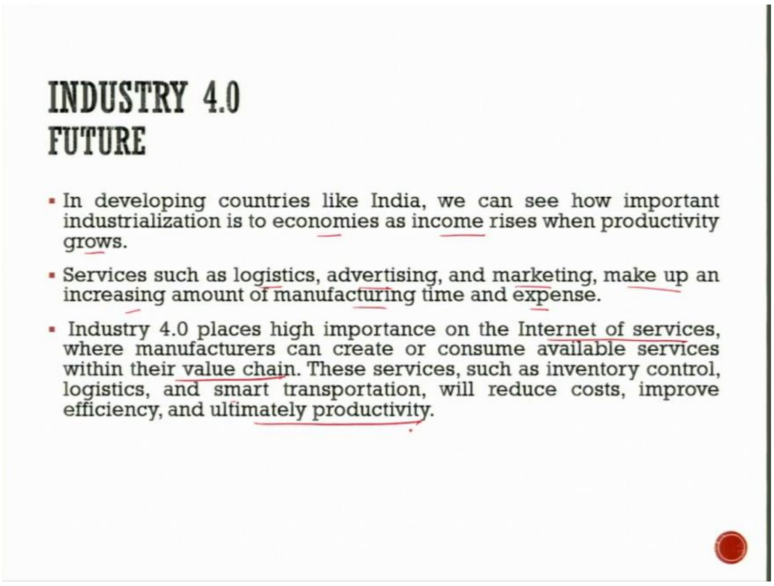

Now, Industry 4.0, the feature in developing countries like India, we can see how important industrialization is to economies as income rises when productivity grows. Services such as logistics, advertising, marketing, makeup and increasing amount of manufacturing time and expense. Industry 4.0 places high importance on the internet of services, where manufacturers can create or consume available services within their value chain. These services such as inventory control, logistics and smart transportation will reduce costs, improve efficiency and ultimately the productivity.

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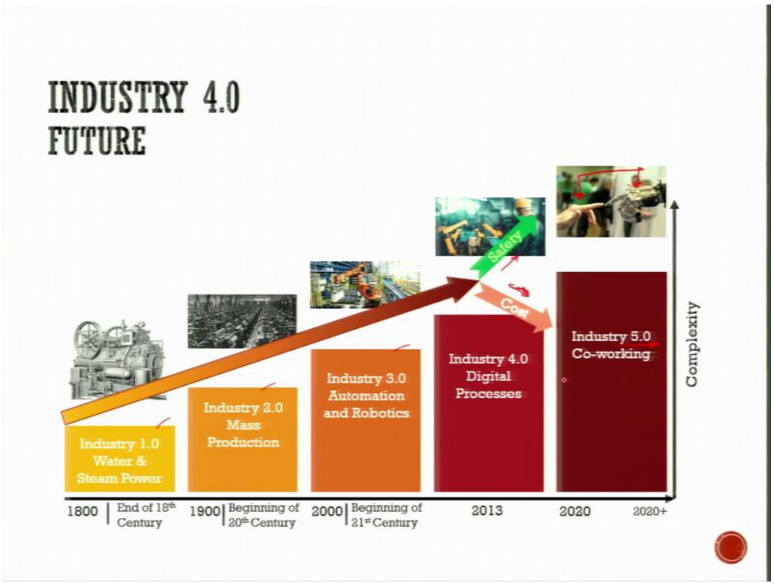

So, how are we working now, and what are we trying to reach to, Industry 1.0, 2.0, 3.0, 4.0, also Industry 5.0, we are co-working, that is the cyber physical systems, which I just talked about, the human and the robots might work together, the cobot systems that might be called as Industry 5.0, that is the safety has to be risen, we need to be more safe, while collaborating, while working with the robots, however the costs have to come low this is the Target or this is what is being approached in the industrial 5.0 scenario.

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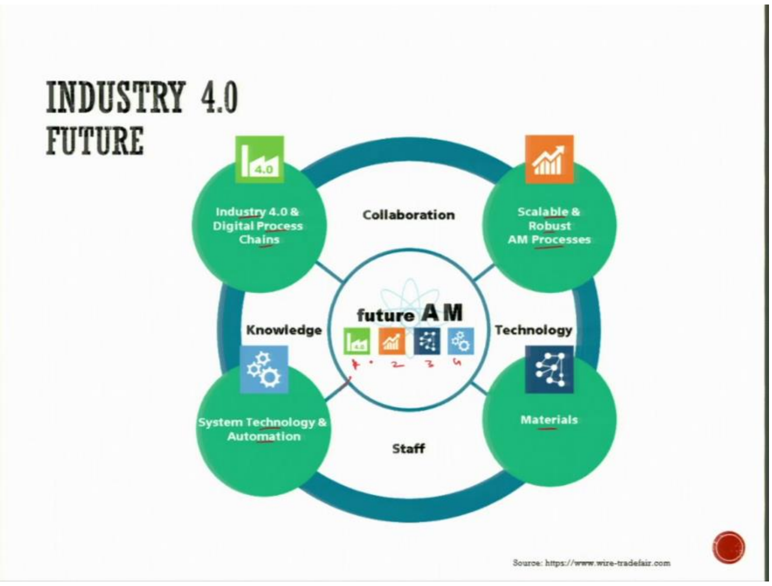

So, feature additive manufacturing if I try to mention here is. So, we have Industry 4.0, digital process change, system technology automation, scalable robust editing, infecting processes and materials, all in one these. All systems are integrated here, 1, 2, 3, 4 and that is the future that will be affecting that is the collaboration of the systems which helps us to have a comprehensive cooperation platform for highly integrated cooperation and use of the decentralized distribution resources. So, this is how it is possible Industry 4.0, digital process changes, the materials, the system technology and automation, all these would help to have a future editing manufacturing system. So, this is also known as a virtual laboratory system.

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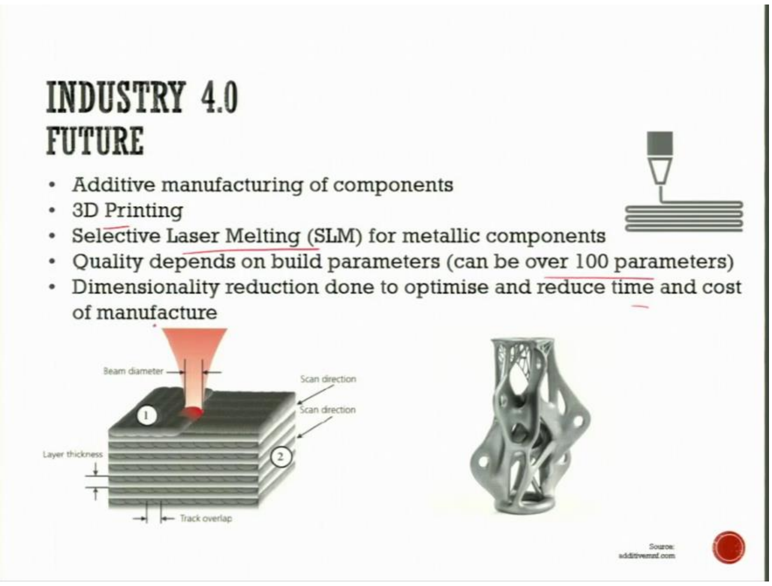

So, if I call the editing reflection components in 3D printing, the selective laser melting suppose as a metallic component. The quality of the build depends upon the parameters that can be over 100 parameters. Dimensionality reduction done to optimize and reduce time and cost of manufacture.

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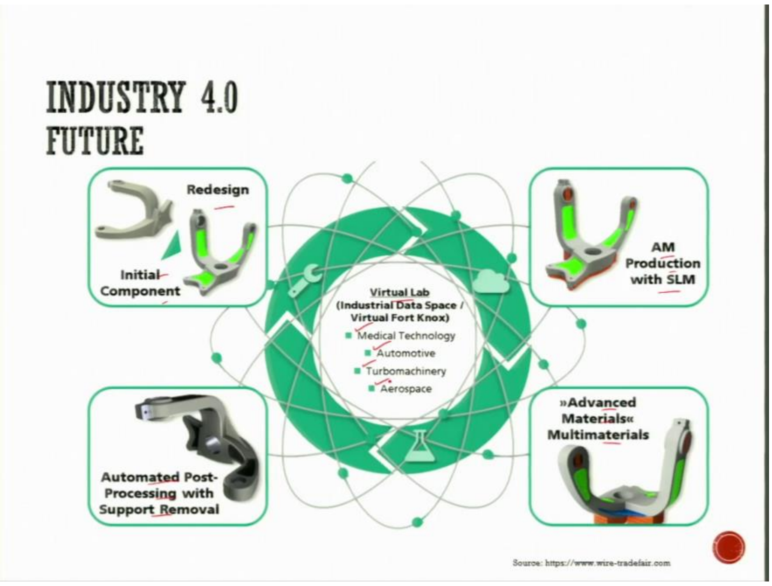

This can be taken further into a virtual laboratory, where you redesign, initial component, additive manufacturing production with the selective laser metering, Advanced Materials, multi materials, automated post processing with support material everything, becomes automated and this could be applied in medical technology, automotive systems, turbo machinery aerospace, so this is how additive manufacturing is connected to Industry 4.0 very closely.

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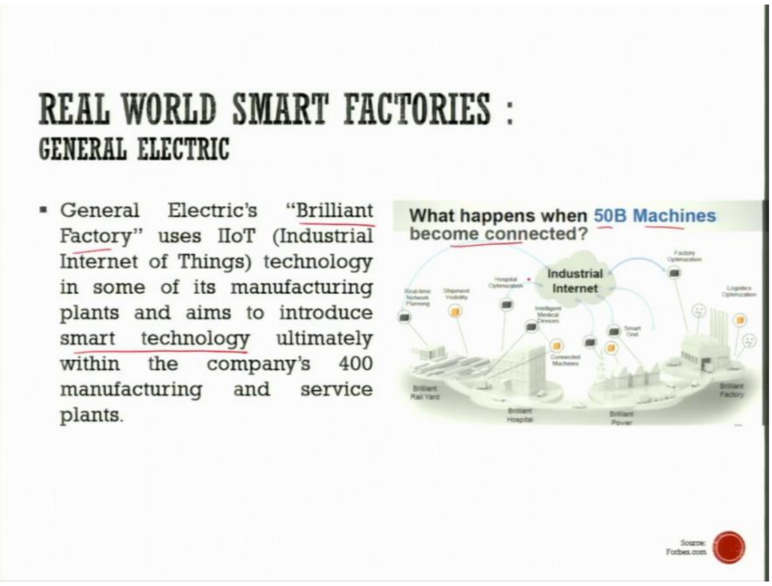

With this, there are certain examples like General Electric, you call it a brilliant Factory that uses industrial Internet of Things technology in some of its manufacturing plants, and aims to introduce small technology ultimately within the company's 400 manufacturing service plants. So, they say that 50 Billion machines becomes connected using the industrial internet of things, not within the plant, not within the room, but across the factories that they have using industrial internet of things.

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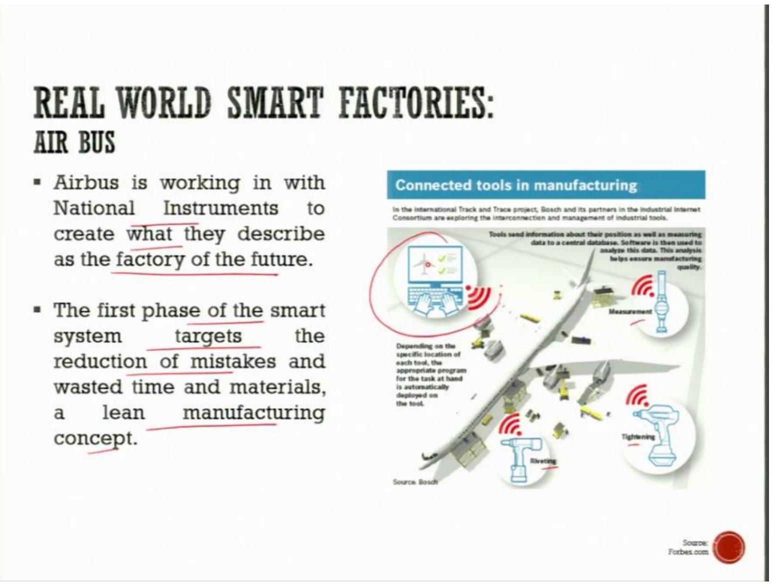

Similarly, Airbus has a connected touring manufacturing it is working with national instruments to create what they describe as a factory of the future. The first phase of the smart system targets the reduction in mistakes and waste of time and material, and lean manufacturing concepts. So, Airbus is also employing the system where riveting, tightening, everything is monitored using the system whether the river the torque is given, whatever force is given for riveting, whatever torque is given of over tightening, everything is being recorded in this system.

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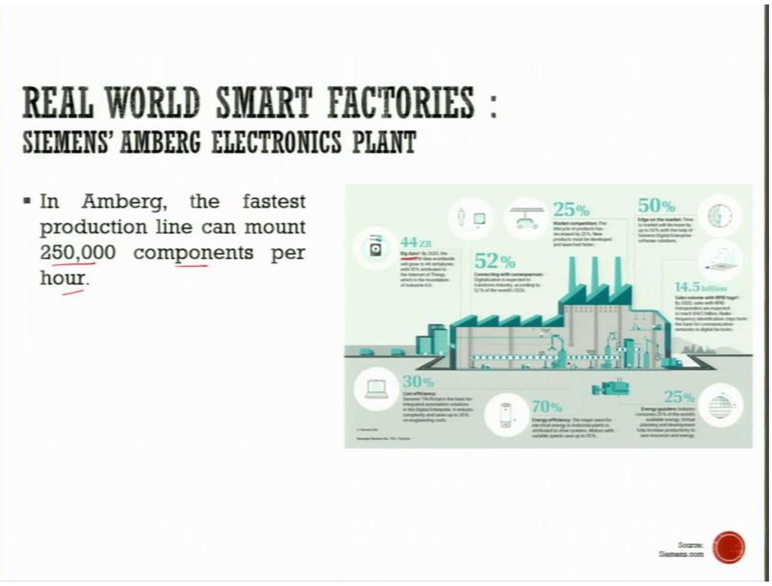

So, these are practical examples, similarly Siemens Amberg electronic plant is the faster production line, and can mount 250,000 components per hour. They also use the system such as the Big Data, the factory internal connection is using the systems, using the server and the physical systems, using the internet of things, using the concepts of the Industry 4.0 and manufacturing.

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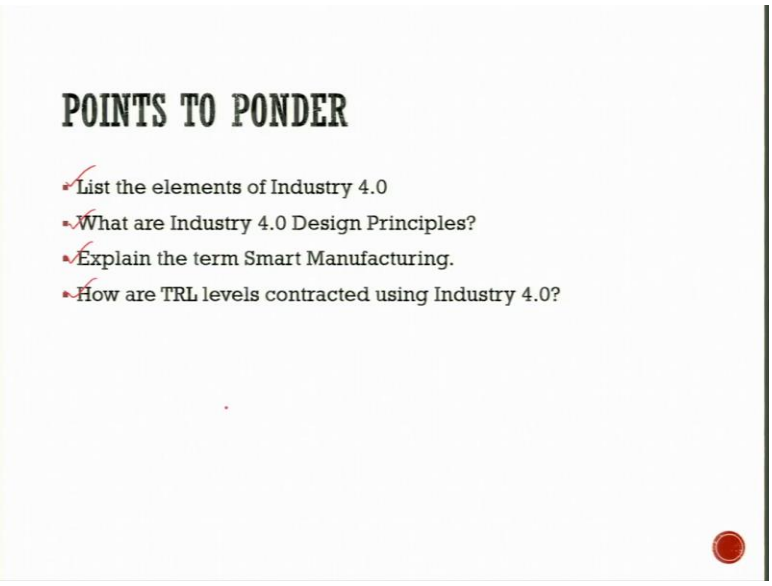

Now you want to ponder in this lecture is list the elements of Industry 4.0. What are Industry 4.0 design principles? Explain the terms smart manufacturing? How are TRA levels contracted using Industry 4.0? With these points if you try to answer, you will be able to understand the contents of this lecture. With this, I try to rest the course on metal additive manufacturing, where we discussed multiple things, I will just have a quick look and summarize what we have discussed through the various weeks.

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In the week one we gave a brief introduction to the metal additive manufacturing, what is metal additive manufacturing? What does this course have? We compare the metal additive manufacturing with the subtractive and need of the additive manufacturing that was given.

Classification of metal additive manufacturing and challenges associated with it, was discussed in the second lecture in which a long-term Game changer or item affection could be. Then current and the future estimation of the size of the market, then challenges and opportunities were given, applications manufacturing was taken as a third lecture.

Then various terms associated with the determine fraction, that is the glossary was given also in the weak 1. Week 2 majorly discussed about that design it is the computer ready design in metal addictive manufacturing, the modelling and data processing. Then we had issues with the SDL file format, the slicing design consideration, machine setup. Then we had the basic processes, starting from the very basic processes, such as the powder bed Fusion methods, that directed energy deposition methods, binder jetting, then some emerging processes such as material Extrusion, material jetting sheet, metal lamination these were discussed.

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Week 3, then started talking about the laser and the Electron Beam processes. In the laser processes the system setup for the laser machines the laser theory in general the components of the razor machine, the difference between continuous and pulsed laser, laser types, laser beam properties were taken. Then we had discussion on the Electron Beam processes, where the difference between the Electron Beam and the laser beam, then Electron Beam powder that Fusion methods, Electron Beam mechanisms were taken.

Week 4, we discussed about the powder and wire fed systems in which the development or the production of powders, the fed delivery and spreading systems, the wire fed systems, everything was discussed. Important physics was discussed in the lecture on solidification of parts, where the cooling curves, the iron carbon diagram, and various metal infract interface diagrams were discussed. For example, we had a discussion on the nickel and medium interfaces, then theory of mechanism and solidification in equilibrium phase in non-equilibrium phase, these things were taken.

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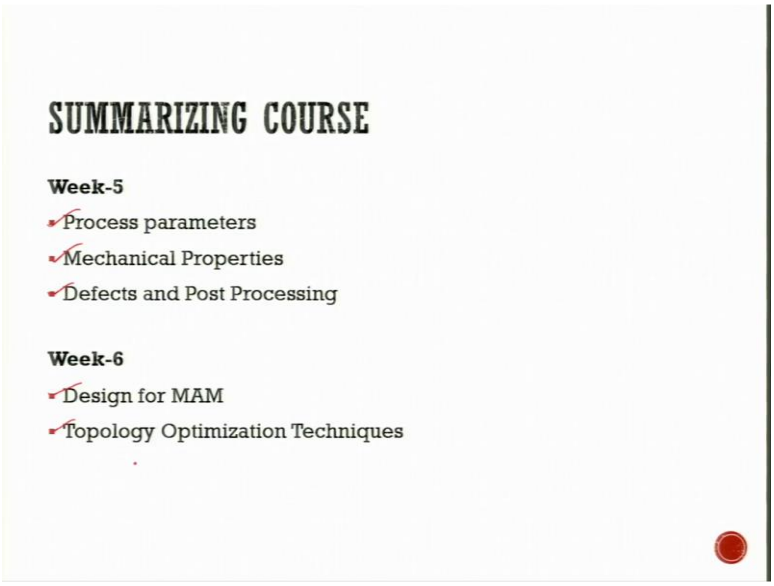

In week 5, the process parameters in general, though the process parameters would be different for different kinds of the systems, but in general for additive manufacturing, the certain process parameters, and there were also discussion on the powder properties for the powder fed Fusion for DED, for bind rejecting all the methods. Then ambient parameters for the powder fed Fusion and the ED methods were taken. Mechanical properties were also discussed in one of the lectures in which the properties such as the hardness, the tensile, and static strength, the fatigue behaviour were taken the common defects in additive manufacturing and the post processing methods additive manufacturing were taken in the next lecture.

Week 6, discussed about design for metal additive manufacturing, in that design it was discussed DfAM, designed for additive manufacturing. Then also we discussed about the modularity, the application field of the design from additive manufacturing, the slicing systems, the design assessment, design making, opportunistic and restrictive designs were taken, topology optimization theory was also introduced in the next lecture, in which how do we reduce the weight reduce the size of the component and how do the CAD software's helps us in that, this was discussed.

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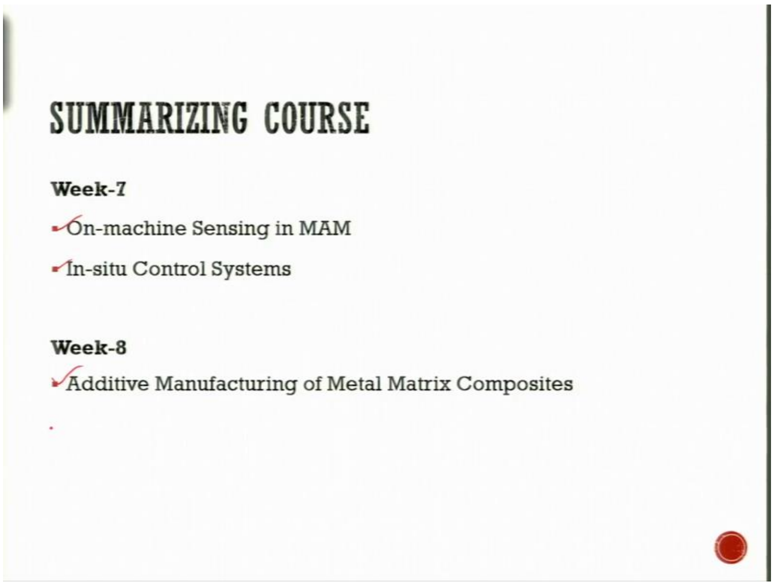

Then in the week 7, on machine sensing and In-situ control system were discussed with the basic principles for the on-machine sensing, factors affecting these systems, specially integrated and specially results sensors were taken. Then we had in the week 8, the additive infection of the metal matrix composites, because hybrid manufacturing is also there in the additive manufacturing system, in which the ferrous metrics, the titanium metrics, aluminium or nickel matrices all those things are there, so these were discussed.

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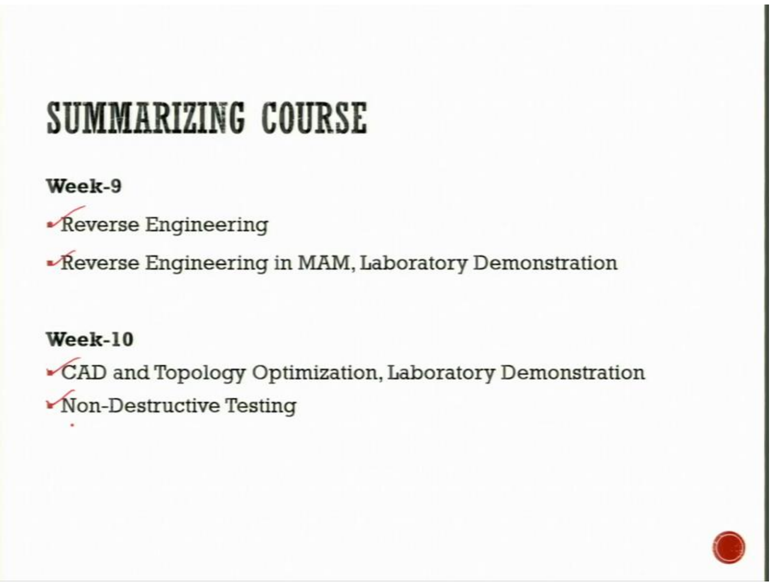

In the week 9, reverse engineering was taken in the reverse engineering, what is the methodology? What are the different steps in reverse engineering? What is the need how do we justify this? Then a laboratory demonstration of this were taken using in the comet 3D 5m scanner, then CAD anthropology, optimization laboratory session was also taken, and a lecture on non-destructive testing in which the contact and non-contact type of the non-restricting testing systems, in the contact type, ultrasonic, adequate magnetic penetrant, acoustic systems were taken in the non-contact radiography, thermographic, visual inspection, X resistances were taken.

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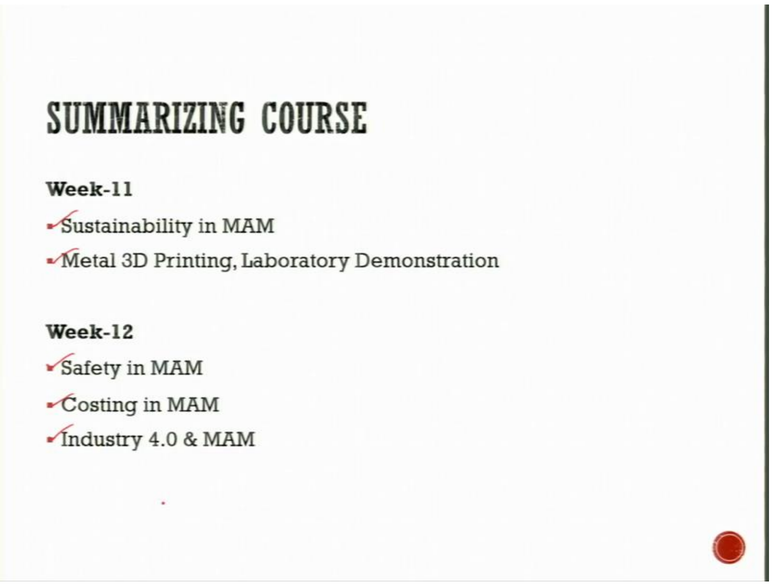

Then we had in the 11th week, the sustainability in additive Manufacturing. In the sustainability how do we develop the green additive manufacturing or the sustainable additive effecting systems, specifically in lean and green business model and design guidelines and design rules for sustainability, these were taken metal 3D printing Laboratories demonstration was then given in the week 11.

In week 12, we had a small discussion on the safety which is very important concern, the kinds of the safety, the inductive and the deductive type of Safety Systems. Then we have this discussion on different models in cost in Metal Addictive manufacturing, in metal detecting where pre-processing processing and post processing costs were taken.

In recent lecture we have Industry 4.0 and Metal Addictive Manufacturing, and how Metal Addictive manufacturing plays a big role in the Industry 4.0 application or implementation, and what future in metal additive manufacturing and Industry 4.0 is there.

With this, I would like to thank you all of you for sparing your time, for being in this course. Knowledge is a continuous process, and we will keep on learning, we will keep on adding more and more to our plate. And this will continue in the future as well, thank you so much.