Computer Aided Decision Systems - Industrial Practices using Big Analytics
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Lecture 39
DSS in Additive Manufacturing

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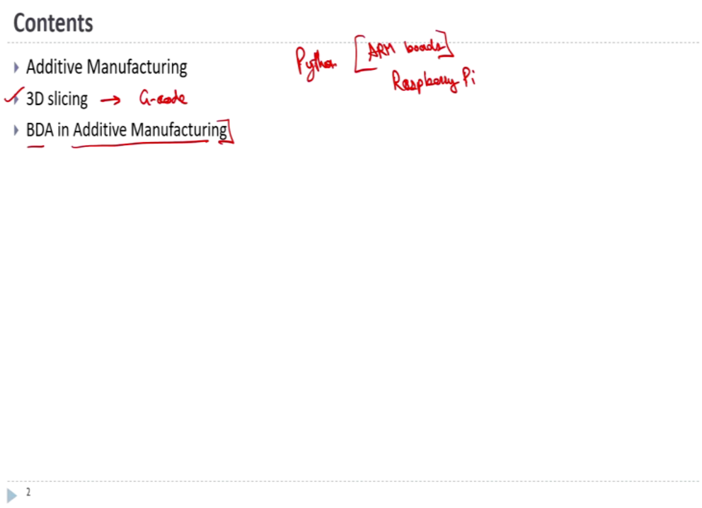

Welcome to the next lecture in the series when we are discussing the Decision Support Systems in manufacturing. I have discussed CAM (Computer Aided Manufacturing) in the last lecture. This lecture would more focus on Decision Support Systems in Additive Manufacturing where we will see along with 3D slicing (we will see) what are the different points to be kept in mind, important tips when we see this slicing is taking and after 3D slicing how do we go to the G-code development from 3D slicing, it is little different, small differences there from the regular CAM program because here it is only done in the slicing board it is not the 3 dimensional movement just goes as it goes in the regular CAM programs.

Then, we will say Big Data Analytics in Additive Manufacturing, a framework we will try to see and will close this week. Additive Manufacturing you might be surprised to understand that there are certain languages which a CNC controller in Additive Manufacturing also uses such as Python. The ARM boards, that are used by the 3D printers or so, are generally these days may be Raspberry Pi or so. We chose Python, which is a high-level language.

So, this modern approach opens a wide range of integration options for the other technology such as we can have costing of that, we can understand or we can write programs to understand, the timing that is for record for the program, timing is proportional to the cost, we can input the material type. According to the material type we can input, we can say based upon this material type this would be the output or this would be the time it will be taken, different thicknesses, everything could be put there. So, this is the difference between the regular CAM and the Additive Manufacturing.

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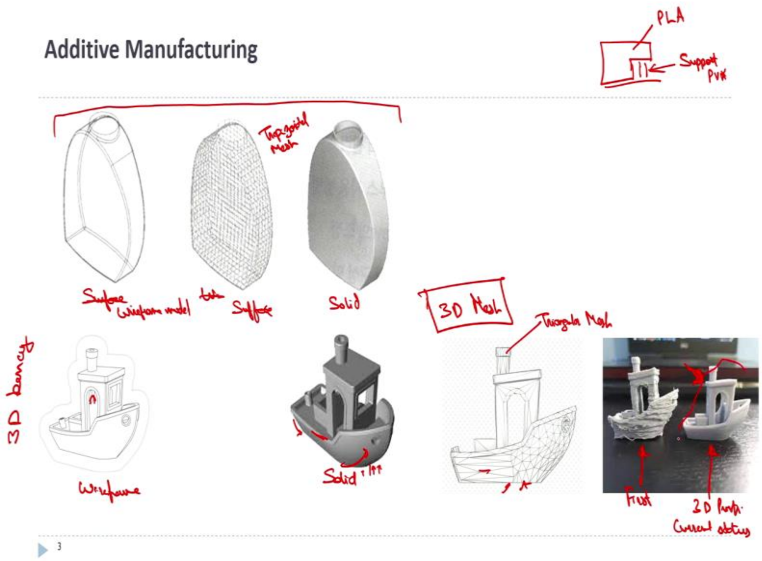

So, here in the last week I saw in the course forum you asked multiple questions regarding the figures for the surface wireframe, it is the other way around. So, (we have) this is our wireframe model. Yes, this is our surface model and this is a solid model for a bottle. This is the wireframe, exactly if we put the wires all along the edges of the pro model, so it shows like this. This is a surface model in which you can see a Mesh, this is not a regular model that is there, here also you can see this is also a wireframe model.

And, this is our solid model, this model is known as 3D bency, to test the capabilities of any 3D printer that is purchased or that you have taken. This is a model 3D bency that helps you to understand what is the capability because you can see it has a specific boundary here, it has a curvature here. And, this is a curvature here, would this be without having any support here because in 3D printing what happens, whenever a cantilever is to be printed. For instance, this model is to be printed in this way, we would need support here, this is known as support. The support material is sometimes taken other than or the build material. For example, if this build material is PLA (Polylactic Acid) the support material might be PVX, something different.

So, this support material is to be removed, so, without support is it, does it support this kind of curve or not and also, we have an open area here. So, with this, with support or without support, how does it manufacture? The 3D bency is a model that helps us to understand the capabilities or the abilities that our printer has. This is a model so what is this, is this a wireframe, is this a surface model? It is not both of them. It is just a Mesh model or we call it a 3D Mesh. Here you could say we had the trapezoidal Mesh. Trapezoidal Mesh in a surface model only. 3D Mesh means wherever required, the density of the Mesh changes. This is a straight material that is why the triangle size is too large here, so this is our triangular Mesh.

So, this is the Mesh program that is used for the Computer Aided Engineering to run the different tests in the simulation program that where the mechanical simulation takes place, this is a 3D bency that was printed, the first 3D bency which was printed, so this is nowadays a general 3D printer, the current status. So, this gives us the capability of how close is our model that is actually built to the bency CAD that we have.

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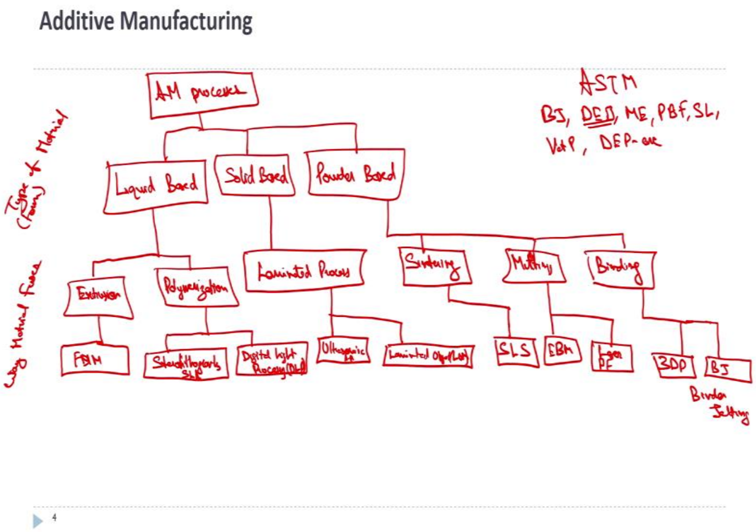

Let us now talk about the general things about Additive Manufacturing. Additive Manufacturing means when we keep on adding the material layer by layer. The difference from subtractive manufacturing is that other CNC machines generally reduce or remove the material. Additive Manufacturing keeps on adding the material and the material is being, when being added it has to be added layer by layer, the different methodologies or different material types that we use in Additive Manufacturing.

If I try to classify the Additive Manufacturing processes, I can say AM processes first is based upon the type of material. Type of material, means the form of material. When I say form, it could be Liquid Based, it could be Solid Based, or it could be in the Powder Form.

So, in all these types the different kinds of processes that we have. For instance, for the liquid width material, when a completely liquid form of material is later solidified, then depending upon the way material fuses. I can put two types for the liquid, one is the Extrusion Process, second is the Polymerization process. And, in the extrusion itself I can say we have a very commonly used process that is FDM or Fused Deposition Modeling.

In Polymerization we have two processes: the Stereolithography which is also known as SLA and when the polymerization happens in the polymers printing or in the plastic 3D printing, it is DLP or Digital Light Processing. In the solid based model is the width material in the solid form that is material is in the sheet form. For instance, if this is a sheet, one sheet is taken, it is cut into the shape, then the second sheet is taken, it is cut into the shape.

So, in the sheet form it always comes and this is a lamination of the sheets over each other, overlapping, and it is cut into a shape. So, in this case the form that I could say is the 'Laminated Process', in which there could be two types. We can have 'Ultrasonic cutting' or we can have 'Laminated Object Manufacturing'.

We have Ultrasonic Additive Manufacturing it is the way the sheets are cut and we have Laminated Object Manufacturing. And, the powder base is also a very important process in which the material is available in the powder form, when it is available in the powder form as we do in the powder metallurgy, we generally only try to coat the powder. If we keep on coating the powder on a base and keep on building a layer of that just to that analogy, we can say a simple Sintering process can be one of the classifications here.

Then, with Sintering we can also melt the powder, then we call it Melting. After Melting we also have Binding. Now, in Sintering we have a process known as SLS that is Selective Laser Sintering. In Melting, we have Electron Beam Melting, it is EBM and also, we have Laser Powder Forming here in Melting. Laser Powder Forming. In the Binding, what you have is 3D Printing and Binder Jetting, we call it 3DP and also, we call one as Binder Jetting. These are the major forms depending on the kind of the material that an Additive Manufacturing process has.

There is another classification that is given by ASTM that is the American Society for Testing and Materials, which has given the set of materials or set of the classification of the 3D printing. They call 3D printing or they have classified 3D printing into seven different categories, which categories such as Binder Jetting as one.

Then, Direct Energy Deposition as second, then Material Extrusion as third, Powder Bed Fusion as fourth, Sheet Lamination as fifth, then VAT polymerization as sixth and Wire arc Additive Manufacturing. Like in welding, we have two different parts. These materials are the same, these are welded using similar material. If the material is different, the welding material is different, that is coming out of the welding torch or so, that is known as Brazing or Soldering. If the material is the same as the joining material and the base material it is welding.

Now if I keep on putting a layer of welding, another layer welding over it, another layer of welding over it, this is known as 'Direct Energy Deposition'. So, they call it 'Direct Energy Deposition' using arc welding. The other DED that is mentioned here is also a Direct Energy Deposition in which we can use a variety of materials including ceramics, metals, polymers, a laser or electric arc or an electron beam gun can also be used here in this DED. Not going into detail of what Additive Manufacturing is.

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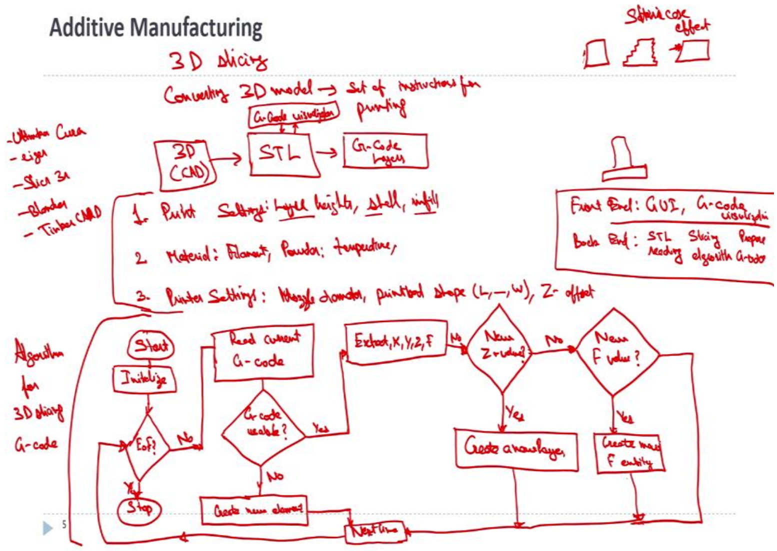

Let us come to the support system phase of it that is the 3D slicing. What is 3D slicing?

3D slicing is an act of converting a 3D model into a set of instructions for printing, this is known as slicing. So, what happens in slicing, we have a solid model which is in the form of a 3D file or I would say a CAD file, this CAD file is converted into an STL file. We call it STL 'Stereolithography'. This is the very base file that is taken which does not have any details of your other dimensions or intricate dimensions within its sight, it is only the surface model is there or the solid model is there.

So, then from STL we try to have the sliced model that we call G-code layers. So here, there are certain points to be kept in mind when we try to slice something or we can say when we do slide or when the slicer software takes a 3D CAD model which is generally an STL format. And, it converts it into a G-code that gives a command for the printer the 3 major types that can be controlled by slicing software, that is:

1) Print Settings which means the Layer heights, Shells, Infill, Infill means if I have a solid model if this is a solid model, the outer surface will be definitely completely filled surface, inside do we need to completely 100 percent filter material or keeping the surfaces completely soft or plain can I have some Infill as 90 percent, 80 percent, 70 percent, can we reduce the material there. This is the Infill. Then Layer heights means

if one layer is maybe of 1 mm, 2 mm, 3 mm, 4 mm, keep on adding a layer of 1 mm each. Depending upon the layer side that also gives me the resolution or the finish of the material into this Z direction. This also gives us the finish that is just for this material. For instance, the finish would not be just very smooth or so, it would be like a staircase finish. Each layer would show some placing or the difference between them. So, nowadays they are printers where you can definitely get in the resin-based printers where the finish is just very close to what we have generally in regular 3D or CNC machines and also the slicing layers are so small up to the order of less than 50 microns per layer height is also there which makes you to feel that the layer is completely soft. So, the staircase effect is not even there, this is the staircase effect. So, print settings are there.

2) Then we have material setting that means the filament or the material that you are trying to use is the temperature. Material whether it is filament, whether it is powder or so. So, what is the temperature in which the filament is melted? For example, in a regular polymer printer that we have in which polymerization happens the printing generally goes to maybe 200 degrees to 20 degrees maximum for ABS it can go to up to 350 degrees or so. For metal 3D printing the material temperature goes up to 2000-degree Centigrade. So, for instance, if you need to have a 3D printing of stainless steel, so, the temperatures could go even high and later when we do the 3D printing using metal it has to first print it, then the material or the unwanted powders which are there, those are to be washed away, then it goes to washer after the washer it is sintered. It is just like baking. When you cook a chapati or roti you first try to dough the flour that you have, you try to make the shape of the dough that you have, then you convert it into roti and put the roti for baking. That is, when it is baked it is sintering, after sintering the material is also small contracted, so that contraction is always compensated in the G-code itself. The 20 percent contraction is in general depending upon the shape of the softwares that are intelligent left to understand what the contraction will be at what point. If the thickness is lesser the contraction would be less, if the thickness is larger the contraction would be more, it is all compensated.

So, these are all taken. Into consideration of the softwares, nowadays of what softwares is there. I will just talk about them. Such as we have Cura as one of the software that is a 3D printing software, very commonly used, also it is made by generally an Ultimaker machine.

It is known as Ultimaker Cura, then a Mark Forged has come up with a software known as Eiger Mark Forged, then we have Slicer 3r, we have Blender, we have Tinker Card and so many different kinds of softwares are available in the market that helps you to conduct the 3D slicing.

3) The third point is the Printer Setting. Print settings were the Layer heights, Shell, Infill, so how do we do it. So, in the printer as well if suppose the layer thickness is required is 50 micron the Nozzle diameter has to be either 50 microns lesser than that, if the nozzle wall diameter is 250 micron or maybe more than that you cannot have a layer less than that, so, Nozzle diameter that is important. Then, we have Print shape or Printbed shape. Printbed means the base where the printing is being carried out. This could be in the shape of a L, this could be flat shape, this could be in a shape of W or so, then we have, what is the offset or in the Z direction what is the offset. So, these important parameters are taken into consideration when we try to convert 3D CAD into a G-code. This is also supported by the visualization, we have G-code visualization, that helps you to understand how the files are being transferred from the 3D CAD to the final printer. In the Front End what we see and in the Back End what we have.

In the Front and what we see is the GUI or the visuals that you have, we see what is the G-code visualization. In the Back End what is happening is reading the STL file and also setting up the Algorithm for slicing, then it prepares the G-code. This is what it looks like. If I try to put the Algorithm for understanding the G-code, I would like to put it like this.

Let us first Start the program, this Algorithm is put into a flowchart form, then we try to Initialize the process, when it is initialized, this is a box, start is my circle or round, then I have a question, in the initial I have a question box whether is it completely ready here or do we do something, if it is ready you say EoF that is End of File, is it okay then we say stop, if it is ready we stop it, if it is not ready, that is no, we go for the next step. The next step is, we convert it into a G-code. It says Read current G-code.

So, this is a box. Again, we have, if the current G-code is ready, we try to create the new element, then comes a question box, we say G-code usable? If it is usable, we go for the next step here, to extract or save the XYZ values from it, so, if it is not usable, we try to write a new element, we say Create new element. After creating a new element, we go to the next line, it is a next line and then again, we try to come from here to either end the file here or try to execute it further.

If the G-code is ready now we need to extract the values from it, extract XYZ or F values. Now, does it have a new Z value? To understand slicing why I am telling Z value only here because slicing is majorly going in the Z direction, in the X and Y direction it is only depositing the material, in the Z direction the majorly the slicing is happening, one slice, second slice. Z direction means your Layer height that you are giving. At one layer it will keep moving in the one plane only keeping the Z constant. Then you give the Layer height a new Z value, then it goes to the next level and keeps on depositing there. So, new Z value is it to be added or not, if yes, if new Z value is to be added, we create a new layer and we try to write the next line and this goes in a loop and tries to stop the program there.

If the Z value is not required then we say it has another F value or any feed new value, I will put a question mark here for the Z value and new F? If yes, we create a new F entity, then we try to go to the next line. This is no, this is also no and if not required then it is definitely, we go to the next line only, so this is our Algorithm for 3D slicing G-code. There are multiple parameters other than the major three that I have put, the print settings, the print material settings or the printer settings.

There are many things to be kept in mind such as the features of the slicing software that is what orientation is the part to be kept in. The part, this part could be built in this form, it could be built in this form, any form the part could be built into a small system. In fact, it could be manufactured in this way or in this way. Wherever we have the minimum time or wherever we feel the strength is better we try to manufacture it in that way. If the Z layer is there, generally the strength of material is lesser or it is weakest in the Z form because the layers are being deposited.

So, it would have more susceptibility of breakage in the Z direction, so this bond would be weaker. So, what happens, we try to tilt it to a 30-degree angle, and we keep it in a corner so that at each direction, this strength is distributed. So, these are the small orientation settings that we also do when we try to consider the 3D slicing.

Then, we have to understand the resolution that is the resolution of the machine which also means what kind of the Layer height that you can keep, these I have already discussed, Infill is discussed. The shapes and types, do we have a functional print, do we have a standard print, functional print means do we have a cubic or gyroid or a standard print could be a grid of triangles or so, do we have a honeycomb structure, all these points could be kept.

So, we have the first layer that is the layer that is stuck to the bed only which could be raft, which could be brim, which could be skirt. So, this layer is it the layer that is to be put just outside the print that is to be there or does the print whole base have to be covered? It depends upon others whether we are putting raft or brim or this is just a skirt only outside only.

So, it depends upon the thickness of the brim that you have put depending upon the material type and also the temperature at which you are working. There are certain parameters like this which are to be considered when we are trying to develop a G-code in 3D printing which are not there in a regular G-code generation in Computer MAdditive Manufacturing or in CNC manufacturing. So, this was regarding the Decision Support Systems in 3D slicing.

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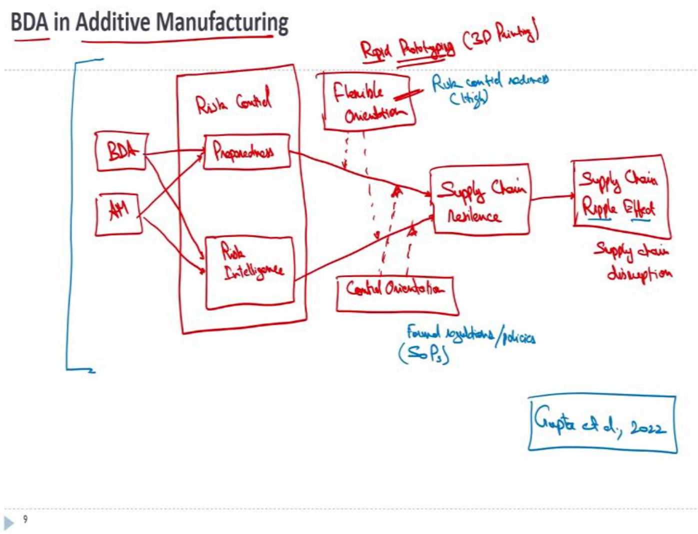

Let us have a quick discussion on Big Data Analytics in Additive Manufacturing. It has been discussed in this course previously as well how Big Data Analytics has been a game changer for various technologies. In Additive Manufacturing also when Big Data Analytics is amalgamated with. We have a drastic change or drastic improvement in the kind of these strategies such as we have this supply chain strategies or supply chain resilience is enhanced.

So, there are certain points that are important to discuss when we try to discuss Additive Manufacturing and Big Data Analytics together. If we try to bring them into one platform, I would say I have BDA here and I have Additive Manufacturing here. There are multiple studies available in the literature, so, I am going to draw a graphic that is taken from a recent study by Professor Gupta and his group in 2022 itself in computers and industrial engineering, this is published., this is published.

In which, when Big Data Analytics and Additive Manufacturing are taken together, that is put it helps us to have a better risk control. Which means we have better preparedness for the risk and also, we have well developed risk intelligence. I would like to bring to your notice a fact that the word Additive Manufacturing or this term came into play later only, when the technology was finally used for production.

And, the products are actually used in real life itself. Earlier the terms used for this was rapid prototyping which means in a general or regular Cer Additive MComputer Additive Manufacturing when you have to manufacture a component, for instance, if you have to manufacture a carburetor, or if you have to manufacture a complex integrated circuits shape or so, what do we need to do?

I need to have a fixture for that, I need to have a jig for that, if I need to manufacture one or two parts of that maybe very minimum number of part, 10 parts of it, 10 pieces of it, so, I have to still require the fixtures, jigs, tools, different kinds of all the setups are required for that. So, this whole system of the tools which was required to manufacture the small number of components was all not required when rapidly we were able to develop it through the 3D printing.

So, that is why Additive Manufacturing has enhanced our risk intelligence and preparedness for the risk is also enhanced. This both put together is our risk control. Now, this study developed a certain hypothesis based upon this: how Big Data helps preparedness or Additive Manufacturing helps in preparedness, how Big Data helps to have a better risk intelligence or Additive Manufacturing helps to have a better risk intelligence and further we had flexible operations? Now, due to increased computational power and development of information.

And, communication technologies in the recent revolution that is the fourth industrial revolution and overflow of Big Data. Big Data is now characterized by its high volume, velocity, variety, variability, and its value proposition; most of the Big Data is produced in real time environments. So, certain internet of things like wireless sensors and networks do provide us with multiple information in Big Data which using Additive Manufacturing has gained popularity and the model is created using computed design in Additive Manufacturing.

So, Big Data has driven Additive Manufacturing while using maybe cloud computing, collaborative manufacturing, the complex diagram handling or real-time analysis, then Additive Manufacturing linked to the Big Data. For example, polymers, ceramics, metals and other cutting-edge materials are used in this technology to create specialized goods.

So, Big Data plays an insignificant role throughout the process and Additive Manufacturing has an additional tool over it. So, multiple industries have now taken a plan to develop the pilot piece first. Using 3D printing, they try to develop the pilot piece and try to take the testing on that piece, only if it is that finally required, then they go for manufacturing or the full production.

Full production, generally nowadays, the regular CNC production is only more economical. Later, it looks like that the Additive Manufacturing will overshoot the regular production when multi jet printing is also there, multi extruder printing is also there. Additive Manufacturing only one of the major cons for this is that the time taken for the print is larger but if we require only one print, definitely, this is the best technology to take into consideration.

So, when we have a better risk, it helps us to have the better readiness of the firm for the risk intelligence and for the better risk intelligence we have better supply chain resilience. With better supply chain resilience, we have something known as supply chain ripple effect. Here also, we have connections between preparedness and the resilience of the supply chain and risk intelligence and the resilience of the supply chain which leads to a supply chain ripple effect.

Supply chain ripple effect is when the supply chain has to be resilient and there are certain strategies to keep it more resilient like we have better inventory and capacity buffers, we try to localize the inventory systems, or we try to have an ecosystem of partnerships, so, we have a better formal regulations and policies as a part of our control orientation.

So, this helps us to have a better control of the supply chain in the case of supply chain disruption. So, to have a better preparedness and risk intelligence there are two terms known as flexible orientation and control orientation which tries to connect to the preparedness and the risk intelligence to help them to associate or enhance the supply chain resilience, so what is this flexible orientation?

By flexible orientation I mean the flexibility that is a crucial component of sustainable operations and for the system to be successful or the system to be completely used in a stable conversion environment. The supply and manufacturing flexibility can significantly lower the production process risks because uncertainty leads to the supply chain risks. The capacity to reduce risk exposure in the event of supply chain disruption can be improved by having flexible orientation, that is our risk control readiness is high, we say risk control readiness is high.

So, we contend that the relationship between the readiness and the supply chain resilience can be strengthened or weakened by the flexible orientation. So, there was a relationship between the risk intelligence and supply chain resilience, which can be strengthened or weakened using the flexible orientation which is put here. Other than that the control orientation, how does this help, this forms a formal regulations and policies.

Formal regulations or policies, which are part of the control orientation. It is crucial to adhere to the company's policies and conduct them appropriately, manufacturing companies typically when they work in the disruptive environments abide by the rules set forth by the management, employees are more concerned with productivity and adapting plans to the internal and external circumstances, so, in every case Standard Operating Procedure that is the SOPs are followed, getting closer to the objectives of the management is set as the main priority.

So, after any disruption that happens in the supply chain. It could be lessened and we have less supply chain ripple effects. So, this all is possible when talking about all connecting to the partnerships, connecting to the people who are working in the system itself or adhering to the policies of the company, this all are part of the Big Data Analytics as well and an Additive Manufacturing we are able to now connect to the different parts and we are trying to able to test what are the systems that we have set are within control or not.

So, with these small illustrations mentioning the connection between Big Data Analytics and Additive Manufacturing, you can definitely read this study by Gupta et al, 2022. Which is in the Journal Computers and Industrial Engineering. With this I will have to stop for this week and Professor Deepu Philip will take you to the HTML syntax. He will try to introduce the HTML codes, small HTML commands and a markup language. How is that useful in having a web-based interface for the program or decision process system that we have developed? Thank you.