The Future of Manufacturing Business:
Role of Additive Manufacturing
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Lecture-03
Manufacturing Processes and Era of Mass Production

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Welcome back. This is session 3 for the course the future of manufacturing. We closed the previous session on this slide, when we got the wisdom from the industrial revolution and pre industrial revolution. Three things which came out explicitly are the economies of scale, the learning curve, and the variety inhibits speed. So, given the technology maybe at that time the lower the variety, the higher is the speed.

So, these wisdom, which comes out at that time was map to different manufacturing processes, which were mapped to different products.

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We have already seen these 4 different types of manufacturing processes. Job shop when we see the iron pillar, steel when we see the batch process, assembly line when we look at that Venice example and when we look at the chemical processes, we looked at the continuous process. So, these are the 4 classical. You can think of even hybrid processes also

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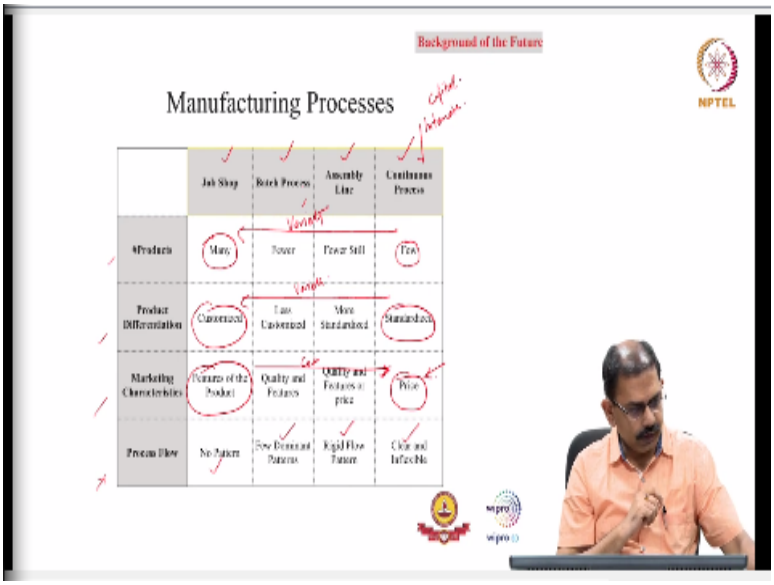

and then these are. We will just look at their main properties. This list can actually in terms of the properties is very exhaustive. I am giving you a very brief description of it. We have 4 processes; one in each column and we have different properties, products, number of products, product differentiation, marketing, and the process flow. If you just look at the continuous

process, we have very the number of products, I am talking about number of products, not the volume, number of products are few.

It means that we are talking about a very less diverse situation but at the same time when we go to a job shop, we are talking about the number of products that maybe even infinite. I can customize each unit. So, in this case, if I have to draw this, the variety goes in this direction and you can see that in terms of differentiation. So, the products will be more or less standard but when I go to a job shop they become more and more customized.

As I mentioned in the previous session, in the end, that we are looking for mass production to mass customization to mass personalization. So, again, in this case, the variety moves in this direction. Now when we talk about the marketing side, you can recall the CIRP definition that marketing is part of it. So, features of the product because now the product is sufficiently differentiated, the feature of the product becomes the marketing USP.

But when I go to the continuous because not much variety, speed may be high, the cost may be low, so the price becomes the USP. In this case, if I go by this logic, the cost may be moving in this direction. If I say I should put that cost on the lower side, so this side the cost is moving on the lower side and because this also makes sense because of the continuous process as we talked earlier may be more capital intensive.

The larger volumes will lower the average cost and when we look at the process flow, so there is no pattern. If I just think of the tire and pillar example, there is no flow there. You can just design in any form, anything can come first. In the batch process, there would be a few dominant patterns. When I go to the assembly line, it may be a rigid flow, it may be rigid for a product.

If you have seen or heard about the automotive platforms, so they are customized for a product. It is a rigid flow pattern for a product and when we go to the continuous, it becomes very clear and inflexible. So, if I talk about flexibility, I think that matches the variety part. So, continuous would not have any flexibility, the process flow would be very inflexible but that the job shop, it is maybe infinitely flexible. So, these form the basic characteristics of these 4 kinds of processes.

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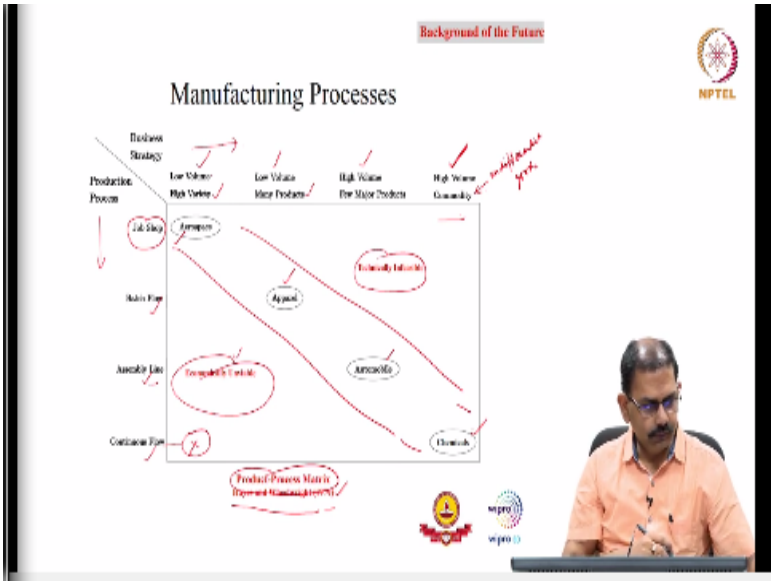

Then there is a very seminal paper an HBR article by Hayes and Wheelwright published in 1979 and what they proposed in that paper is called the product-process matrix. If you look at the top there is a business strategy. We are talking about maybe high volume in this case high volume is a commodity. When I say commodity in fact in economics we normally look at undifferentiated goods. When I talk about low volume may be talking about many products.

There is some kind of a tradeoff between volume and variety I think that this particular matrix tries to do that and it tries to map the process to the product. Production processes are given in this direction and the business strategy. If you are looking for a high volume maybe a commodity kind of a product you should go for a continuous flow and the example as we have seen is chemicals.

If I am looking for automobiles I should go for an assembly line. It is a high volume and a few major products. If I have to go for apparel I think the previous figure talks about that on this one. I should look for a batch flow and when I go for an aerospace kind of a product, it should be in the job shop.

It actually tries to map a product to a process and you can actually see the part. When I talk about aerospace it may have low volume but maybe high variety because you have to customize maybe

each product to the requirement and when I talk about chemicals they may have not much variety but you are looking for high volumes. So, we actually are moving remaining ourselves more in this diagonal.

This side of the diagonal it is economically unviable. You can actually relate to that capital in intensive investment. So, if I am using a continuous flow and if I am looking at low volume and high variety, it does not make sense to use a continuous process for it. So, the lower side of this particular figure, it is normally economically unviable and this may be technically infeasible because the current technology may say that with job shop if you want high variety, you cannot have high volume at the same time.

I think that is where we really want to move. I should have a manufacturing process that produce high variety as well as high volume. So, the cost part, so the 4 goals can actually be achieved. There are a lot of researches on this. There was a paper in fact I think a lot of people have worked on that I have just taken one of them, that they observed that most factories who do not upgrade close to the diagonal

they actually perform well and which are not which try to not follow this diagonal. They try to be off the diagonal, their performance is actually not good. What has been proposed by Hayes and Wheelwright actually has been observed in practice also. This particular matrix is actually very relevant how you actually map a process to maybe different types of products. So, technically infeasible and economically unviable. But now the question is can we do better.

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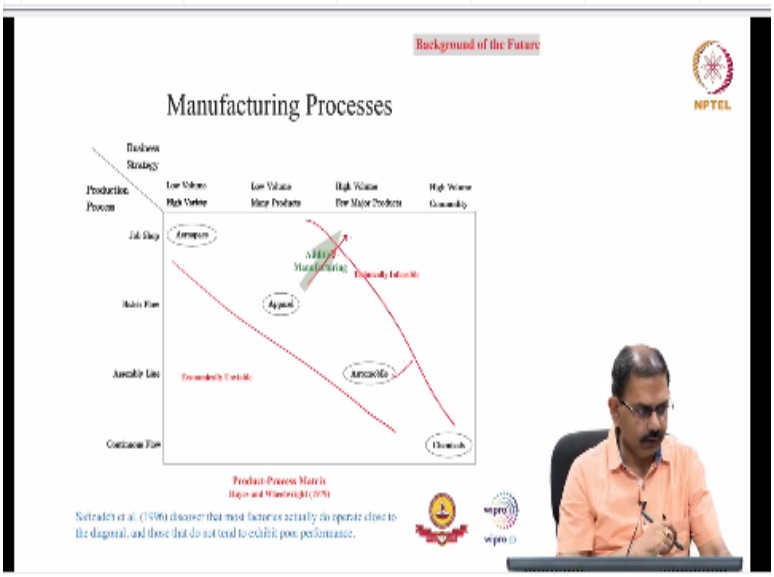

Now, I added his simple point here, that whether this diagonal can be expanded. Can I move in this direction, may be additive manufacturing can allow me to talk about, maybe high volume or maybe moderate volumes with high variety. I certainly move out from low volume high variety to move in this direction, whether the technology allows me to do that. It is not just the technology of additive manufacturing. I think what it needs is the whole ecosystem.

Whether the use of IoT, whether the use of blockchain, and whether the use of reconfiguring supply chains and the whole procurement. We may use words like cloud manufacturing, cooperative manufacturing. All these integrations of these technologies may allow me to move in this direction. This particular matrix, the modifications of it will be very relevant for this course. If you just again see this particular thing that we are mapping an automobile to the assembly line.

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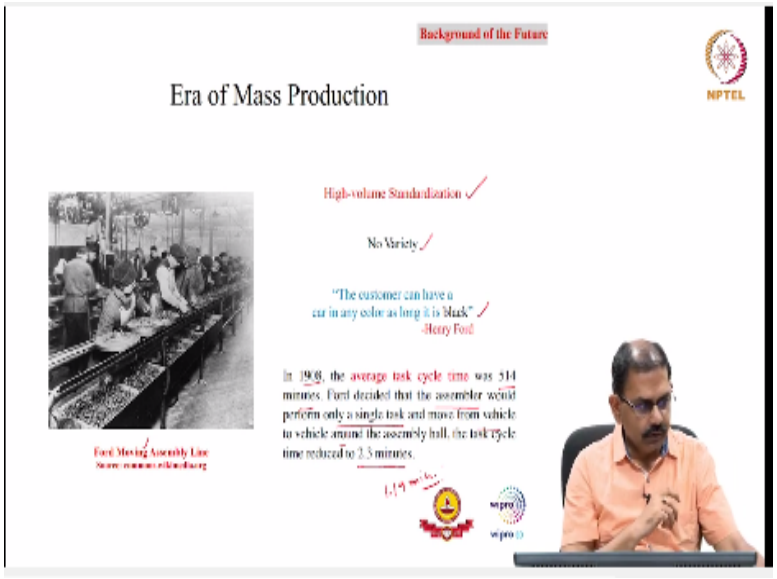

This idea starts with mass production. So, now we are talking about the era of mass production. This particular figure what is the picture shown to you is from the Ford moving assembly line. Now as I mentioned earlier that Ford tries to integrate those wisdom what we have seen earlier. At the start of the session, I was just talking about wisdom which is part of the industrial revolution, economies of scale, learning curve, and variety in a bit speed.

All these things achieved in this era of mass production and the Ford motor is a pioneer in using all these ideas. In the ship example, if you recall, we talked about the low volume. Now we are talking about high volume standard products. No variety, in fact, Ford is a very famous quotation the customer can have a car in any color as long as it is black.

In fact, the Model T was only produced in black color and the use of black color also has an impact on productivity because they found that the black actually dries the fastest. So, any other color you can talk about red, you can think of green but they were using black only because it dries the fastest. So, these ideas form so interchangeable parts all these things will come because of the learning curve, the high volume will take care of the economies of a scale, variety will improve; no variety will improve the speed. The average cycle time was 514 minutes in 1908. This idea of the learning curve that an assembler would perform an only a single task and the vehicle will move around the assembly hall. The cycle time was reduced to 2.3 minutes.

The assembler will move from vehicle to vehicle, the cycle time move from 514 minutes to 2.3 minutes. So, you can see the impact of the ideas of learning curve. Then the moving assembly line comes in, which I think if I recall correctly reduce the cycle time to 1.19 minutes. In this case the assembler will not move, the vehicle will come, so that productivity will improve.

You can actually see these ideas, how these ideas became integral part of evolution of manufacturing. what it actually brought on the table?

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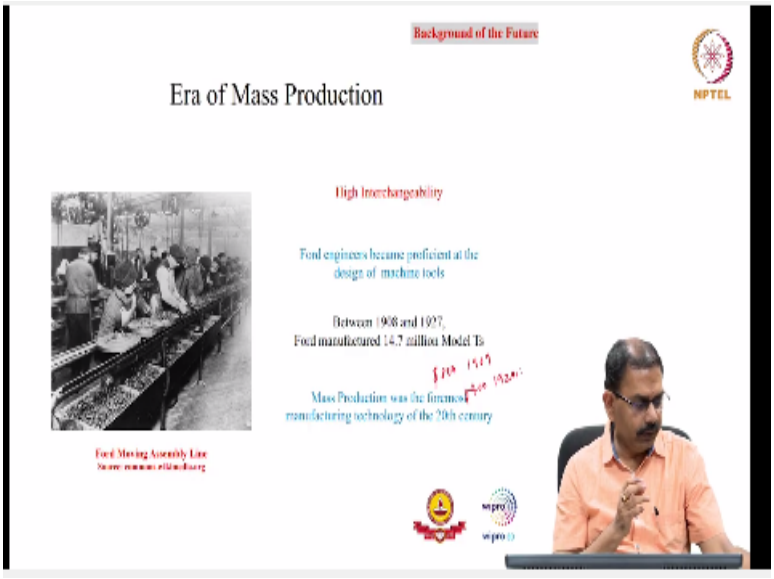

It in fact brought many things, so as I mentioned about high interchangeability, the learning curve becomes significant dominant there and at the same time they were also very proficient in the design of the machine tools. You actually can look at these numbers. They manufactured about 14.7 million model T's in those 20 years and maybe they were actually talking about car for every American.

If I recall the data correctly, I think a dollar 800 car in 1909 may become about dollar 400 car, maybe by 1920s. So, all these ideas of economies of a scale, learning curve, and variety inhibits the speed has significantly impacted the cost and the cost of the product may be reduced by half. When we talk about say Tata Nano, we were talking about 2000 dollar car maybe in 2000s.

But Ford actually as achieved that number may be the 400 dollars may have a different value at that time. The cost significantly came down and it looks like that every American actually can buy a car. These ideas propelled manufacturing significantly and mass production became the foremost manufacturing technology of the 20th century. In fact, these number what I told you about 400 dollars or something, they would have come down even further.

I think the data that I am showing is only for 1909 and 1920s. So, the idea of no variety, economies of scale, and high interchangeability allowed Ford to reach these numbers. But then as a consumer will you always prefer to have a black car. In fact, when we go in, try to buy a car today, we always look for more options, we may look for more customization.

I may look for something which is customized for me, so I may not cost is only one part of the story. In fact, if you can start thinking about the scale part, marketing dominance also came with this idea. Marketing is a functional area because if you really want high volumes you really want high demand. So, marketing and operations actually start going in sync with each other.

You can actually have low cost only when you actually have high volumes, and when you have high volumes you need high demand. But the question here is when productivity improves the overall income of the citizens improves. In that case, they may look for more variety, they may not be happy with having just the black car.

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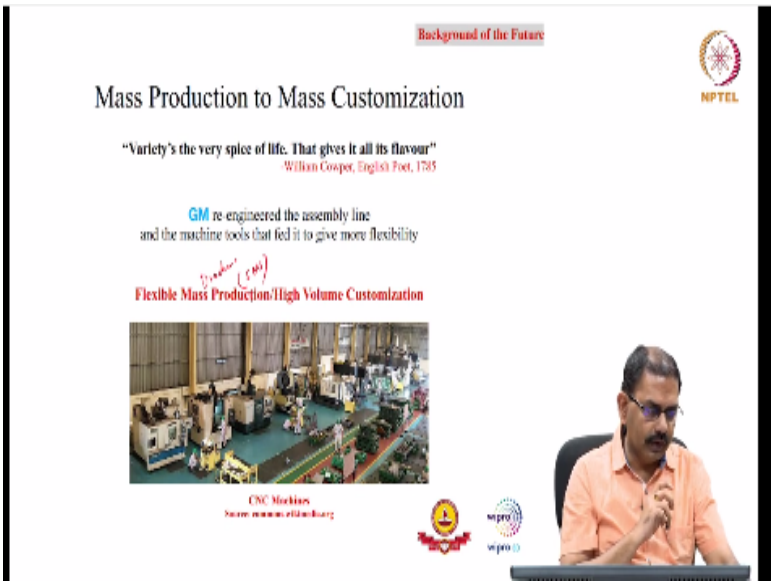

This a start making the things move from the mass production to mass customization but we are still talking everything in terms of mass, we are still talking in terms of high volume. Say economies of scale is always applicable. There is a very interesting, again I am continuing with from coupling I am coming to another British poet. Varieties are the spice of life and that gives it all it is flavor. So from Ford, the things move.

The theater of production moves from Ford may still be producing a lot of cars but in terms of variety, GM came at the forefront. They try to reengineer the whole assembly line and they try to improve the machine tools to bring more flexibility and I think one of the very famous management guru Peter Drucker. He coined this word as is still talking about mass production but he is now calling it flexible mass production or we call it FMS.

Now we are talking about mass customization or high volume customization. They started more emphasis on numerical controls or maybe computerized numerical controls, CNC machines, and NC machines. You can actually produce better and better machine tools that can improve the customization. So, the era of mass production which have its own benefit.

Now we are not happy with the no variety. What we want is, we are moving in the direction of having some variety but then there could be an impact in terms of cost, then there could be an impact in terms of speed, and there could be an impact in terms of quality. But for the time

being, I think whether it is Ford whether it is GM, they were actually maintaining reasonably good quality.

Only caveat there was that at least in GM thing that there was ample inventory because you really want variety and that actually shoot up the cost.

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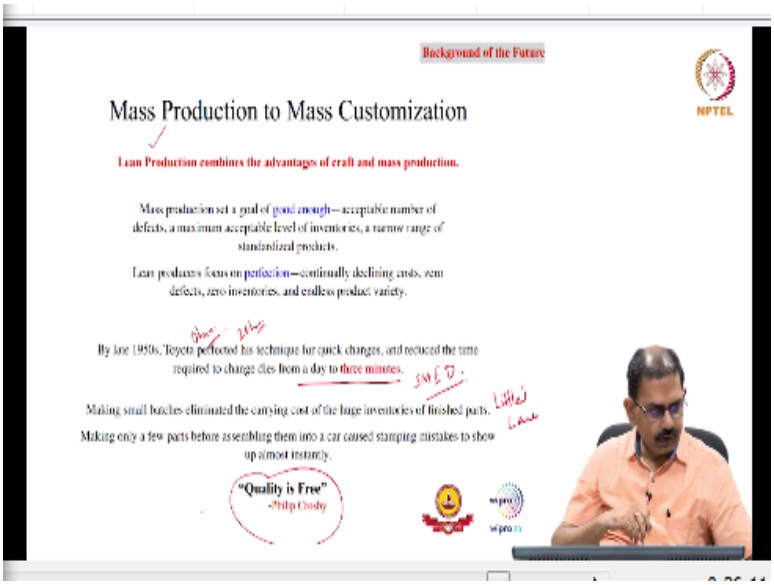

This thing continues from GM, the theater of production moves to Japan. We are still talking about mass customization but now something becomes significant and that significance comes in form of maybe a new type of mass customization which we call as lean production. This word was in fact, lean production came I will talk about that.

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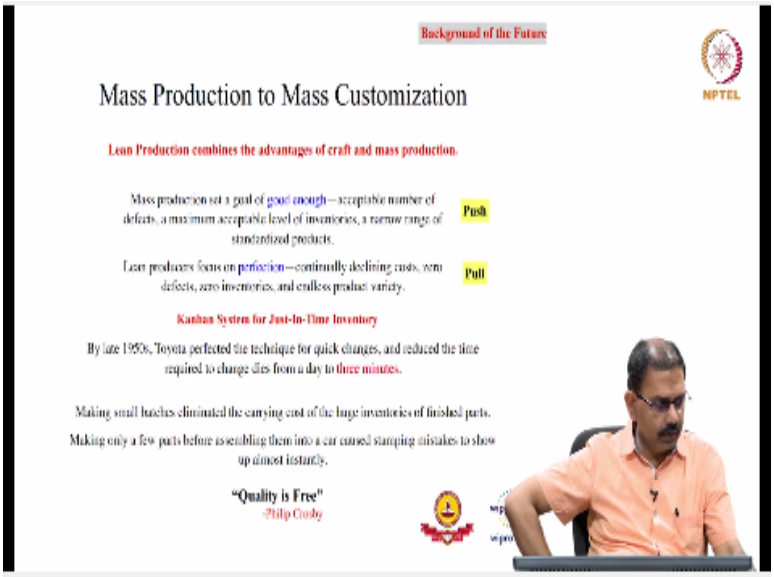

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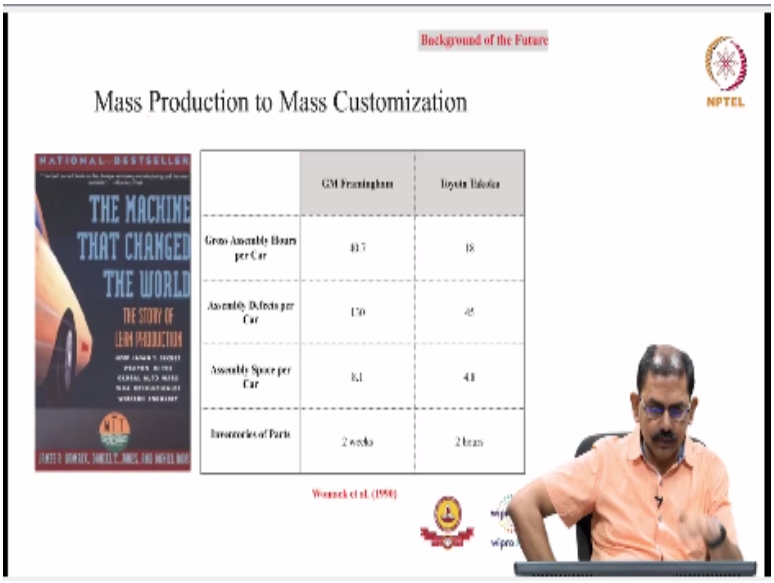

Yeah, this book, the machine that changed the world. So, this word was first coined in this book, the story of lean production. If you just look at the difference between the Ford and the GE model, mass production set a goal of good enough. They have emphasis on quality but they are not looking for perfection, acceptable number of defects, a maximum acceptable level of inventories, and narrow range of standardized products.

Now, these things were improved in lean production system. They start emphasizing on perfection. They are looking for the zero kind of scenario that zero defects, zero inventories, and endless product variety. So, how they actually did that? You recall that the canon example we

talked about the setup time. So, what Toyota, in fact their industry engineer was Ohno. He is the main person behind all the innovations which happened at Toyota.

What they observed in fact what Ono observed that the setup time, so if you want to move from one product to the other one, you have to change those dyes and sometimes time could be 24 hours. So, it becomes like the setup cost. If you are moving from one to the other product, the setup cost was very high, so that is where the idea of batch comes in.

Once you put something you continue to produce that, and then once you have a single batch done, then you move to the other range of the product. What the main contribution comes in? Can we actually reduce the setup time and what they actually found that what they innovate will actually reduce the setup time from a day to about 3 minutes.

In fact, this word of single minute exchange of dye comes from them. Your flexibility becomes very high. I can actually produce one type of Maruti then I move to the other one because the setup time maybe only 3 minutes even I can reduce it even further. What it actually brings on the table? There are 2 important things; making small batches eliminated the cost of carrying huge inventories.

As I mentioned earlier in the Ford and the GM there would be a batch because the setup time was high. Now because the setup time has drastically reduced, so you can actually produce in small batches which eliminated the cost of carrying inventories and this may be very interesting because we are going to correlate to a law of nature which we call the Little's law.

People, who have actually studied in operations management, they might have heard about it. We are going to relate this whole notion of how the setup time reduction will lead to low inventories. The second significant impact is that because you were actually making very few parts, the quality improves. Any mistakes were actually easily observable.

In fact the Philip Crosby announced the quality is free. George Stigler said flexibility is not free, now he is saying that quality is free and again that question is always there can you actually achieve flexibility, can I make flexibility also free.

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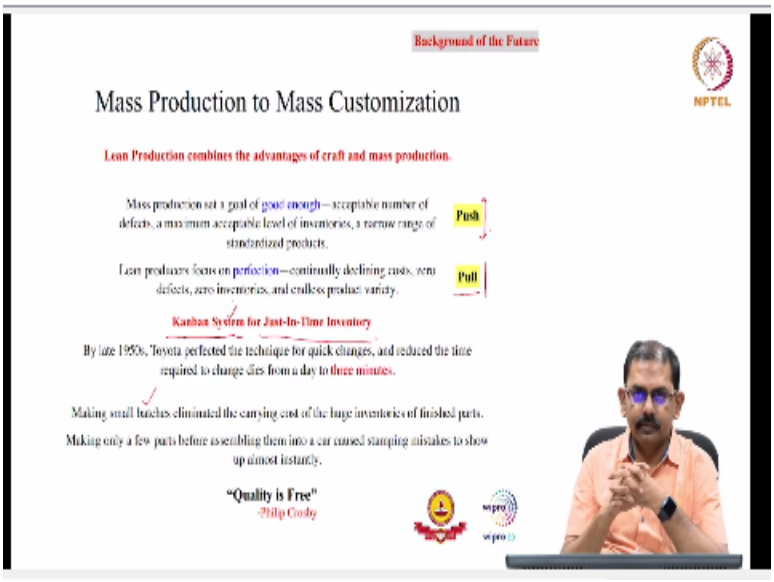

There are other dimensions to this problem because along with lean came what we call is the just-in-time inventory and that came because of this Kanban system. It means that you actually of the right inventory, it does not say zero inventory. I need the right amount of inventory, so that none of my assembly line or the process should be sort of the work-in-process.

But how you signal that you are actually, now need the inventory and for that thing, they invented a process which they call is the Kanban system. So, the Ford system or the mass production systems were mainly the push. It means that you do not bother about what is actually happening on the downstream side. You just follow the process whatever if the batch size you keep on producing.

Quality will be taken care of only at the end but in the Toyota production system we are talking about a pull system and to pull we need this Kanban thing that is to signal to the upstream that now the inventory actually has to come. This is the other innovation that happened in the Toyota production system and all these things assimilate into this idea that quality you can actually achieve at no cost.

But again now you can actually see that we are moving in the right direction, we are still talking about high volume production. It means that your cost would be low, in fact, in this case, the cost may be even lower because the inventories have come down, your speed may still be the same. So, in terms of the technical definition, I can call it the throughput.

The quality has significantly improved and we are also improving the variety. So, if I just start comparing those 4 goals, the mass customization is actually making me in the right direction, moving the things in the right direction. It certainly has a big impact on the way we actually think about manufacturing but then again the most important question is always this, can I do better.

Can there be more advances in technology that can actually allow us to even improve the Toyota production system? So, with this, I will conclude this particular session. In the next session, we are going to talk about the remaining portion of, so we talked about mass customization we will be going to mass personalization. We will be talking about more on the business models.

We will also look at the technical definition; what is the economies of scale, economies of scope, and economies of unscale and how these things are changing the manufacturing paradigms. With this, I will conclude this session. Thank you.