

**The Future of Manufacturing Business:
Role of Additive Manufacturing
Prof. R. K. Amit
Department of Management Studies
Indian Institute of Technology-Madras**

**Lecture-02
Manufacturing and Industrial Revolution**

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Background of the Future

Manufacturing in Pre-Industrial Revolution

"Gold is for the mistress – silver for the maid –
Copper for the craftsman cunning at his trade."
"Good!" said the Baron, sitting in his hall,
"But Iron – Cold Iron – is master of them all."
— Rudyard Kipling

Smelting is used to make iron from iron oxide
It has been known for about 5000 years for making copper and zinc

In 1200 BCE, smelting process was modified to make iron
This led to decrease of prices of iron by 97%

Steel was discovered around the same time
In 200 BCE, China was making steel using blast furnaces

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Welcome to session 2. If you recall, in the previous session we were talking about background of the future. **(Refer Slide Time: 00:24)**

Background of the Future

What is Manufacturing?

Enterprise's Replicator
Self-assemble atoms into food and drink

"Tea. Earl Grey. Hot."
Captain Picard in
Star Trek: The Next Generation

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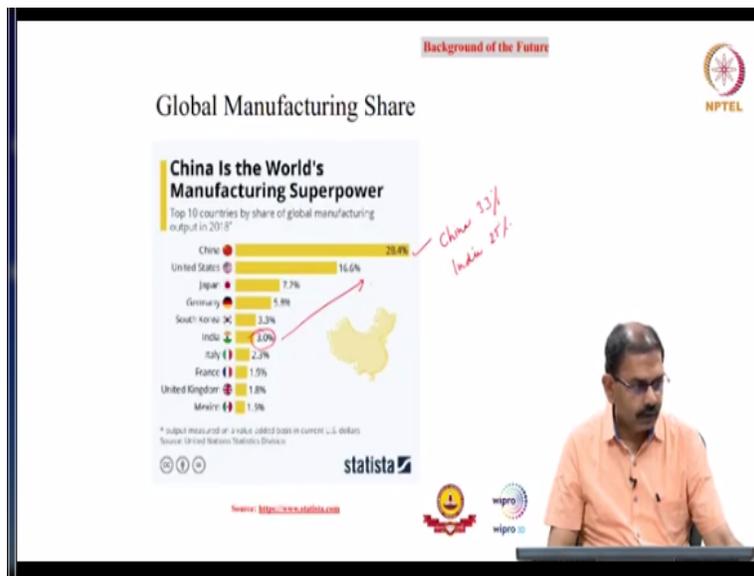
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Then we looked at numbers for India and US compared those numbers and then we also talked about the importance of manufacturing for employment.

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Background of the Future



Manufacturing in Pre-Industrial Revolution

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We stopped in the previous session somewhere here, when we were talking about manufacturing in pre industrial revolution. I will continue my discussion here because we were talking about the iron refining.

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Background of the Future



Manufacturing in Pre-Industrial Revolution



Rust-resistant composition of the metals used in its construction

The iron pillar in India was manufactured by the forge welding of pieces of wrought iron.

Unique Products
Jai Shree

Iron Pillar, Delhi



One of the things which you might have seen or you might have heard about it is the iron pillar in Delhi. This exists maybe for more than 2000 years. I think it was located somewhere else and it now sits somewhere close to Qutub Minar. There are some goodness properties that it has survived for more than 2000 years in an exposed environment. It does rust resistance and infact the metal they use as maybe the wrought iron, where the carbon content is very small. It is used by using forge welding of pieces of wrought iron. So, a lot of people have worked on

finding what is the metal composition, what kind of technology which allowed it to survive for so long. I know one of my earlier colleagues at IIT Kanpur was significantly working on mainly this iron pillar.

If you just look at this particular pillar, it is said standalone pillar. So, you do not see many replicas of it. You do not see this may be in a mass production kind of setting. You can replicate them but I do not see it is that easy to replicate and you may not get the replica of it, you may always get a variant of it. We are talking about this product as a unique product, and this process through which it is manufactured, we call those processes job shops, so we will discuss those things.

I am now integrating some bit of manufacturing and some bit of operations management. Now if I just compared to those 4 classical goals. When we talk about standalone products, they may not be economical at all. If I just think in terms of the scale part, I have to get all the resources only for this particular product or for this particular piece and even the speed part may not be there because this is a unique product. There would be a lot of learning as we start making it.

You rule out the speed part, you rule out the cost part, you can talk about diversity here because if assume that someone wants a pillar, not just iron maybe something else or maybe a different height or a different shape. I can always do customization of this. You can talk about maybe diverse or high variety and maybe high quality because this product in fact has the time is the proof in this case.

If the objective is to keep it rust-resistant for maybe more than 2000 years, it certainly has served that purpose. It is not cheap, it is not fast but it is diverse or it may be diverse and it is of high quality. That is something which we normally associate with job shops but where the question here is can we improve on these objectives. Is it possible for me to maintain this diversity to maintain this quality but improve the speed and improve the cost also? You actually can produce something which is cheap, fast, better and diverse.

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Background of the Future

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Manufacturing in Pre-Industrial Revolution



Arsenal in Venice
Source: <https://www.italianonline.com>

Arabic word
dar-as-sina means workshop

Building Ships
for the Venetian Navy

First Documented
Assembly Line

Low-volume
Standardization

Learning Curve



This takes us maybe to about 1500 years later than this iron pillar even more than that. So, I am coming to medieval times and I am moving from India to the city of Venice. There is an arsenal in Venice, which is used to build navy ships. The origin of this Arsenal is coming from an Arabic word which is a dar-as-sina, which means, a workshop.

If you see this, we are talking about another kind of manufacturing process which is nothing but the assembly line. I can say it is a moving assembly line, you would see a variant of it as we go into the automotive moving assembly line mainly for companies like Ford. So, you may start building something here, it keeps on moving, the mass will put weapons, ropes, anchor.

What do you see is that the goods are moving? All the other things remain stationary. That is why it is called a moving assembly line. The similar thing that you see in the automotive as I mentioned earlier. Now we are talking about low volume standardization, what it means is that you are improving the variety. When I say improving it means that when we talk about a as I talk about earlier about the Ford assembly line when I talked about mass production.

There was no variety at all but in this case, there is some variety and what it is doing is that there would be interchangeable parts. It means that mass is (08:20) put at one point. This particular operation will be they are only experts in this. Someone, who is putting the weapons they will be

expert only in this. So, we are actually observing what we may call as a learning curve, we will talk about that.

There could be some cost savings because of replication. Someone who is doing the things, again and again, the cost would come down, but this is still a low volume because the volume of the number of ships was not very high. When I go to an automotive assembly line, I will say that it becomes a high volume standardization. This is the first documented assembly line and this idea of learning curve will extend into modern times also.

Now, if I just ask the same question that what is happening in terms of cost, in terms of speed, in terms of quality, in terms of diversity, suddenly the speed would be higher because people are now experienced. As I mentioned in the iron pillar example, there would be learning as you start manufacturing something but in this case that learning has come already. So, the speed would be higher as the cost will come down because of this learning.

There would be a learning curve effect, so cost may also be lower. Diversity suddenly has come down because now we are talking about low volume standard products. So, you cannot make all kinds of products. Quality will be reasonable. They may not be that could be debatable but for timing let us just believe that this has survived more than 2000 years.

We are not sure whether we can say the same about the quality in this case. Quality may be reasonable but certainly, the cost and the speed has improved, diversity has come down. You can start looking at the tradeoffs already. All these 4 things cannot be achieved at the same time. As of now, we are not saying that these 4 are impossible to achieve together.

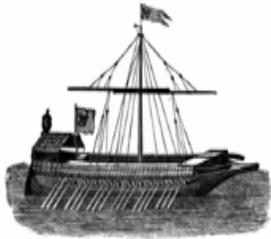
I think the flow of the course would go in the direction where it is possible to start thinking that all these 4 goals can be achieved on the same day. One thing which comes again, here is, so in the Chinese example when we talk about the blast furnace, we were talking about economies of scale and now we are talking about the learning curve.

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Manufacturing in Pre-Industrial Revolution



Interchangeable Parts
Permits variation ✓

Venetian Galley
Source: commons.wikimedia.org



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I will just show you one ship which is coming out of this Arsenal. Interchangeable parts and it permits variation, so this becomes important. When I talk about low volume standardization I am talking about interchangeable parts and I think the Americans have expertise complete in this when they go to the modern assembly line. This is a manufacturing in the pre Industrial revolution; I will continue with this, we will give you one more example.

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Background of the Future

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Manufacturing in Pre-Industrial Revolution



32-Pounder Cannon, 1805
Source: commons.wikimedia.org

Higher rate of fire ✓
Less set-up time ✓

Battle of Trafalgar



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This is from a battle which was fought between the Britishers and the French. This was in 1805 and this canon is called as the 32 pounder canon. In this battle in terms of the numbers, the Britishers were on the lower side compared to the French but eventually the British won the battle because of this particular canon. This is an advantage because it is a higher rate of fire.

This concept is crucial because the setup time for the next fire was very small in this particular case. So, the technology became relevant again that you actually can reduce the setup time for the next fire. This concept of setup time, we are going to see significantly in this course, that whether the technology can reduce the setup time substantially.

Then there are some laws of manufacturing which relate the setup thing to how much inventory would be there. Setup time reduction is important in the context of manufacturing. It will impact inventory, it will also impact the speed. When it reduces inventory it will improve the cost, when the setup times goes down, the speed also goes up.

All these, if you just start building the concepts, we have economies of a scale, we have learning curve, we have the setup time. All these things keep coming together. So, I am going to combine all these ideas, all these concepts together and we start looking into how we can improve manufacturing by using these concepts.

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Now we move from the pre industrial revolution to the industrial revolution. A very interesting book by William Rosen, it is the most powerful idea. I have taken a quotation from there which talks about the industrial revolution and what he claims is the most important invention of the industrial revolution was the invention itself.

Because what we are seeing is not an invention of one good, one technology, and one product, you see maybe a series of inventions. It generates that idea that you actually can invent anything. These days we talk about disruption, disruptive technologies and lot of people talk about disruptive technologies. They may not just come in a standalone form.

I cannot say just artificial intelligence, I cannot just say block chain, I cannot just say additive manufacturing, what we are going to see how these technologies interact and when they interact, they may end up in the exponential form. So, I think those ideas are also important. When I talk about William Rosen quotation it is talks about the, so if you just look at, this is a very famous authorities water fame.

The industrial revolution first mainly came in cotton thread. When I look at those numbers, pre industrial revolution as I mentioned India's contribution was 25%. So, we were pioneers in cotton thread. Most of the garments everything was made in India. The first hit for Indian manufacturing was the invention of this Arkwright water frame.

It is claimed to be the first true production machine which is driven by water and it may be close to a continuous process. This is another manufacturing process. We have seen job shop, we have seen assembly line and it produces nothing but the cotton thread. This maybe the first initial ideas of industrial revolution.

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Background of the Future


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Manufacturing and the Industrial Revolution



Bessemer Converter
Source: commons.wikimedia.org

Sir Henry Bessemer commented
"The new process used powerful machinery
whereby a great deal of labour will be save,
and the steelmaking process will be greatly expedited"

Andrew Carnegie used Bessemer converter
and other complementary ideas to make Carnegie
Steel as the biggest producer of steel by 1899


Batch Process

Steel became the catalyst of growth





This extends further. This may be the fourth manufacturing process, the batch process. This came mainly for the steel and this brings a still, we talked about iron. I am continuing with the Kipling's poem that iron and steel forms the catalyst of growth and this may be true even today. Whenever we talk about we may be looking at different types of steel or iron.

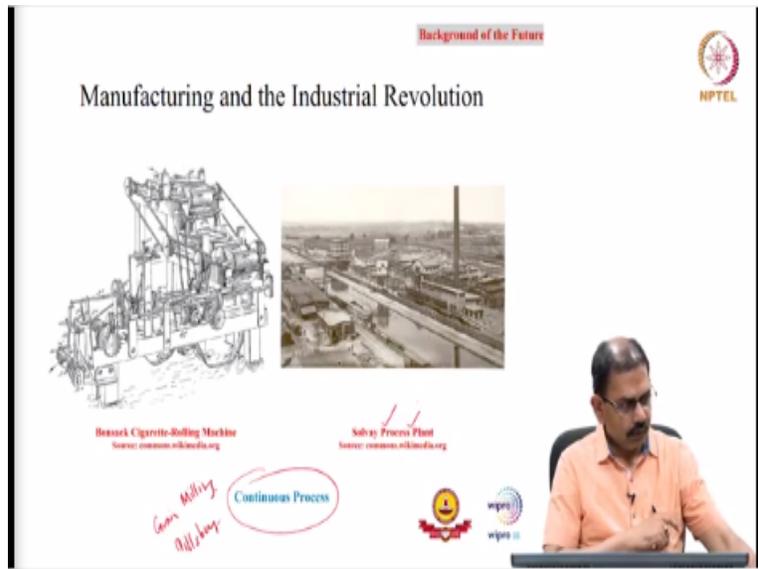
But I think in terms of the material usage they still are the dominant ones. This converter, so if you just look at this particular thing, what it says is, so we are talking about the speed now. Steel making process will become faster and Andrew Carnegie uses this converter and he brought some more complementary ideas to produce the steel as a batch process.

Economies of scale all those ideas they combined, blast furnaces and by 1899 the Carnegie steel became the largest steel producer in the world. The cost also substantially reduced. You can see the benefits of what scale actually can bring and maybe matching the right product with the right process. So, we are going to talk about that.

This is one of the major leap during the industrial revolution, that you actually can. Steel becomes back end of most of the things. We are going to talk about say steam, electricity, maybe computers right now, we are talking about digitization. These maybe different general purpose technologies which have impacted different eras of industrial revolution, industry 1.0, industry 2.0, industry 3.0, and industry 4.0.

At the same time as a general purpose technologies steel also is contributed significantly. May not be today but at least in industry 1.0 steel became one of the major movers. These ideas keep on rolling, I think as we mentioned that invention itself was the prime invention during the industrial revolution.

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We keep on seeing the difference of, so we talked about that cotton thread example. So, we keep on seeing more inventions, and then we go to a different process. We have seen that in cotton thread the continuous process. Some of you might have watched, maybe food factory on National geographic or Discovery, you would see that most of the processes they use are continuous process.

Simple processes which produce say only ice creams. The initial examples of continuous process were the green milling and a company like Pillsbury comes out of it. There is no variety at all, so what do you produce is just the same thing. You see the examples of chemicals. You might have heard about the Solvay process to produce alkalis.

This is Solvay process plant. Solvay brothers had started the plant in US. These are all continuous process. The advantage comes because of, there is no variety. Now, if I just again compare those 4 objectives because there is no variety, the learning effects may be substantial

but only disadvantage of these things it is capital intensive. So, when I talk about a continuous process, it is pretty capital intensive. It actually makes sense to produce in large volumes.

The cost divided for the units and that is where we try to have a continuous process for high volume products which are needed in high volume. When we talk about a volume certainly in that case, the variety part goes off but they maybe fast. Because of low variety they maybe high volumes. The cost will come down if there are high volumes, no variety, and the quality may also be good because there may be a good control on the process. So, what we have learned in this case that we have seen 4 different processes from the job shop to assembly line to a batch process to a continuous process. These form the 4 traditional manufacturing processes and the important part is how we actually map them to different types of products. I think that is what is going to come now.

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Manufacturing and the Industrial Revolution

"Large is Beautiful"

The more is produced, the cost goes down

Economies of Scale ✓

The more often a process is repeated, the cost goes down and the quality goes up

Learning Curve ✓

"Machines with interchangeable parts can now be constructed with great economy of effort. Witness the humble typewriter, or the movie camera, or the automobile....The world has arrived at an age of cheap complex devices of great reliability; and something is bound to come of it."

-Vannevar Bush, *As We May Think*, 1945

"Variety inhibits speed"

Speaker: A man in an orange shirt and glasses is visible in the bottom right corner of the slide.

Before I go into that mapping, I just want to take wisdom from what we have learned till now. The one thing which comes out very significantly in the whole discussion that large is beautiful. We have seen right from Chinese blast furnace example, that when you actually scale the things up, the cost goes down maybe the other objectives will suffer but the cost significantly goes down.

The more is produced, the cost goes down and we actually call it economies of a scale. We are going to look this in technical sense also but for time being this is the wisdom that the more you produce and the volume goes up, the cost comes down when we call it the economies of scale or the scale effects. Then there is also a learning part which says that the more often if processes repeated, the cost goes down and the quality goes up.

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The slide is titled "Manufacturing in Pre-Industrial Revolution" and is part of a presentation titled "Background of the Future" by NPTEL. It features a quote by Rulyard Kipling: "Gold is for the mistress – silver for the maid – Copper for the craftsman cunning at his trade." "Good!" said the Baron, sitting in his hall, "But Iron – Cold Iron – is master of them all." Below the quote, it states: "Smelting is used to make iron from iron oxide. It has been known for about 5000 years for making copper and zinc. In 1200 BCE, smelting process was modified to make iron. This led to decrease of prices of iron by 97%. Steel was discovered around the same time. In 200 BCE, China was making steel using blast furnaces." The slide also includes the NPTEL logo and a small image of a speaker in the bottom right corner.

I think this particular thing we have seen in our shipbuilding example, when we talk about the interchangeable parts. It means that the same operation is repeated multiple times and the learning effect comes in which may be missing in the iron pillar example. You would actually see that the cost comes down and the quality goes up and this is actually an example of what we call as learning curve.

In fact, if I recall correctly there was an aerospace engineer Paul Wright, who tried to estimate the learning curve effect in the aircraft manufacturing. He estimated that if you double the aircraft production, the cost will actually come down by 20% for each aircraft. So, that is the kind of scale effects or learning effects we are talking. So, this is been summarized well in a very famous article written by Professor Bush as, we may think, in 1945.

I request everyone actually should read this; it gives the glimpse of technology. Machines with interchangeable parts can now be constructed with great economy for afford, witness the humble

typewriter or movie camera or the automobile. The world has arrived at the age of cheap complex devices of greater reliability rates. We are talking about quality now and something is bound to come of it.

This is something which has been told in 1945 when all these affects have already been observed. One thing which has again come out that the lower the variety, the higher is the speed of manufacturing. If I can find a way to lower the variety then or if I want low variety I can achieve high speed.

The tradeoff will be in terms of whether you want high variety. So, when we talk about business, we talk about business strategy. Some companies leverage variety, it means that their USP to produce high variety. They may not bother too much about the speed side, but some companies will look at the cost as a strategy, they may not worry too much about variety, they may look for speed.

If I recall the Ford example, Ford tried to forego variety. He does not want variety, but he wants high speed. So, they call tensions between these 4 goals will always be there. But again, the question here is whether the modern technology allows us to achieve all these 4 at the same time. With this I will conclude this session, in the next session we are going to talk about how the manufacturing processes are optimally map to different types of products.

Our discussion will also move to looking at defining what mass production is, what is mass customization and mass personalization. Our next session would be on those topics. Thank you.