Corrosion, Environmental Degradation and Surface Engineering
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Lecture – 35
Quantification of Economic Losses caused by Corrosion Degradation

Hello and welcome to the course on corrosion, environmental degradation, and surface engineering. This is the last lecture of this course. This is lecture 32, and we will treat it as a continuation of the 31st lecture, where we also discussed the economic losses resulting from corrosion degradation. Here, we are attempting to quantify the economic losses that are caused by corrosion degradation. What exactly is corrosion, and how can we effectively prevent its degradation? We have previously discussed technologies related to anti-corrosion. We say there are coatings that can prevent or may delay the degradation.

We employ various surface treatments, including surface design, which is itself a form of surface treatment. Additionally, we use corrosion-resistant materials, selecting those that offer superior protection against corrosion. To further mitigate corrosion, we may use inhibitors, which can be effective even in the presence of chloride ions, acetic acid, or moisture. Nano additives have become well-known for their ability to enhance corrosion resistance in such environments. While this course doesn't cover the use of oils and greases in detail, they are also valuable for protection. When applied to a surface, oils and greases create a barrier that reduces exposure to moisture and, to some extent, acids, thereby protecting the underlying metal from corrosion.

Therefore, these oils and greases significantly aid in minimizing corrosion and reducing resistance or degradation. Now suppose you can buy any rolling element bearing; we generally use calcium-based grease. The basic purpose of calcium-based grease is to prevent water infiltration. It provides a certain level of sealing to the bearings. You can use that type of oil and grease.

We also gain knowledge about cathodic protection, which involves providing a treatment that prevents the anode from evaporating into atoms or iron, thereby significantly reducing progress and minimising degradation. Now, the question arises: given the abundance of technologies, what is the actual impact on overall economics and why is it being affected? In our previous lectures, we learned that a developed country experienced a GDP loss of approximately 3 percent due to environmental corrosion or degradation. So, we are trying to understand what the real role of this technology is. Therefore, by examining the top 10 largest economies, we can gain a deeper understanding of each country's specific roles. In this case, I have listed the USA as number 1, China as number 2, Japan as number 3, Japan as number 4, and India as number 5.

These are the top 5 economies even in this literature, which we have picked up from the Forbes India that they describe around the top 10 economies, but I am just looking at the 5 top economies. Now when they have given data in the form of the GDP per capita also. The USA holds the highest GDP per capita, followed by China, Japan, and India, with a narrow margin separating them. In terms of GDP per capita, the United States ranks first, followed by Germany at number two. In this case, Japan ranks third, China ranks fourth, and India ranks fifth.

Therefore, the only difference between China and Japan as a whole country is in overall economics. China comes to number 2 on overall economics or economy, while Germany comes to number 2 from a from a GDP per capita point of view, and China comes to number 4. Therefore, the rankings for numbers 2 and 4, as well as those for 1, 3, and 5, remain unchanged. So why are we discussing these economies? Because we are trying to understand why the economies of these 5 countries are among the top 5. Let's start by observing that the USA typically adopts highly advanced technologies, also known as cutting-edge technologies. Additionally, they conduct a wide range of research and participate in various sectors.

Now, let's turn our attention to China, which boasts a robust manufacturing hub. So they are really excellent at manufacturing in these states, and then they have very good policies, which is what we call the export focus policy. Then they also have to spend a lot of money on infrastructure. So they have substantial infrastructure. This explains why they are ranked number two.

Now, let's move on to Japan, a country known for its innovative and technical practices. Japan boasts a workforce that is highly skilled. They also boast a diverse range of industries such as the automotive, electronics, and machinery sectors, with a strong focus on research and development (R&D) and efficiency. Despite their small size, they are the third largest economy in the world. Regarding the Germans, they are already recognized for their precision work and precision engineering.

They also have industries that are related to vehicle manufacturing or production. They also prioritize high-quality exports. It is not all export. They only make high-quality exports. They share Japan's commitment to innovation.

They have a strong infrastructure, and they also have a skilled workforce. These factors contribute to their overall strong economic position. Coming to the fifth India, India has a good domestic consumption. That means if we are taking a policy in India or maybe start manufacturing everything in India, we will turn out to be a big economy as such. That means development within all the development within India itself will lead us in a much bigger manner.

When we have a robust service industry, particularly in the field of information technology, our economy can flourish. So these are the reasons why we are now maybe India is a fifth number in an overall economy. When we discuss all this, we often find that there is a significant workforce requirement, similar to what is seen in Japan and Germany. We possess a skilled workforce, which is a significant asset. This means that overall skill development plays a crucial role.

The second aspect pertains to technology, specifically cutting-edge technology. This course has taught us that we can continuously enhance our technology through a data-driven approach. We gather data, identify potential problems ahead of time, and then proceed to implement these advanced technologies. Therefore, if we possess comprehensive knowledge, possess the ability to execute and implement, and, on top of that, develop a policy or management approach, India can also make significant progress. This is because India has a significant amount of domestic consumption, and if everything is manufactured in India, the economy will flourish as expected. So this is a reason why it has been mentioned now. The lecture topic is quantification.

What are those quantification methods? In the previous lecture, we discussed a variety of approaches to cost evaluation. We introduced a willing method, and we say how method, and the last one was the input output method. Of course, the input-output method is very rigorous and requires a lot of data. How method is also kind of a synaptic, which we use in creative problem-solving method. They chase only one sector or subsector and try to dig out all the information.

This approach follows a type of vertical thinking, where we delve deeper and deeper to gather more information. One common method is to classify costs into direct and indirect categories, often involving significant approximations.

For instance, one key approximation assumes that if corrosion, such as rusting, occurs with materials like iron and simple steel (not stainless steel), these materials could have been used for a wide range of applications. However, due to their vulnerability to corrosion, we often opt for alternatives. When using materials other than iron or simple steel in situations prone to corrosion, the cost associated with that switch is attributed to corrosion. This assumption explains why iron and steel, being highly susceptible to corrosion, lead to a preference for non-ferrous metals or alloy steels. Therefore, if we can calculate the overall cost of using these non-ferrous metals or alloy steels, it would represent the direct economic loss caused by corrosion.

So this is the important thing. Additionally, let's assume that we are using materials such as iron and steel, but we are also incorporating some protective measures. What are those protective measures? We are applying a coating, such as paint or phosphating, to the surface. Those measures can also be accounted for. So that is why they take whatever the paints are in a manufacturer or produce in the country; 50% of that more or less will be utilized for the corrosion resistance to avoid the corrosion.

If I am familiar with the data pertaining to paints manufactured or synthesized in a particular country, I would estimate that 50% of these costs are directly related to corrosion. Another thing is the cost related to shut down over designing, loss of the output because we are not able to run the machine, and some sort of efficiency loss, accidents, or some sort of contamination because of the wear loss or because of the corrosion losses, those kinds of things. That comes in the form of indirect losses. So we can really try to quantify. The Eulerian method assumes that whatever the direct cost equivalent is, there will also be an indirect cost. Therefore, we assume a 50% direct cost and a 50% indirect cost. However, this is an assumption made by the author, who is genuinely attempting to solve this problem.

So next one case study I am going to discuss where they assume 50-50. And why are we saying these are indirect causes and related? The reason is that these all effects are creating some sort of harmful effect, and that too on operational procedures, which is decreasing the productivity, which is increasing the downtime, and then creating more and more risk, and that means that is what is the safety risk-related thing. So this is the first method, the kind of good, some approximation, but gives some relation, some output. So at least we are able to realize and understand, and to some extent we are getting quantification.

On a how method, we have a more quantification, slightly better quantification. If I use a creative problem-solving method, brainstorming, I say okay is a one, but synaptic, where we choose one problem and then try to go vertically down and then explore more and more. So the same thing in the how method happens on that. According to the methodology, it is recommended to concentrate solely on a particular industrial sector. I can select a specific industry, such as agriculture. In agriculture, I can select a specific subsector, such as machinery, and then investigate potential corrosion issues within this sector.

Even if I manage to enter a subsector, can I determine whether the corrosion is caused by sand, soil, or water? I can effectively navigate in a vertical direction to gather the most comprehensive information. In this case, we will focus on a specific industrial sector to calculate the corrosion cost. Now what are those costs? One of the costs is a direct expenditure that is directly related to the corrosion.

They also point out that the costs of countermeasures, such as coatings, should be included in the overall expenditure. First, there's the direct cost caused by corrosion, and then there’s the cost of preventing it, which must also be considered. Additionally, they include expenses for research, data collection, and data analysis related to corrosion. This provides a comprehensive approach to understanding the full scope of corrosion-related costs.
By evaluating all the associated costs, better decisions can be made. Their method involves examining the entire corrosion process, even down to the elemental level, identifying areas prone to corrosion, and then developing solutions. They also assess the potential damage caused by corrosion and the resulting financial loss. This is an example of a deep, focused approach, often referred to as a synaptic approach, where they explore one topic in detail to fully understand it.

To elaborate further, direct corrosion costs include expenses related to replacing or repairing damaged equipment and structures. For instance, if a piece of equipment is completely damaged and needs replacement, or if it requires repairs, these costs are considered. In addition to this, there are other associated costs, such as acquisition costs when ordering new materials, labor costs for installation or repairs, and maintenance costs. If a machine or system is shut down during part replacement, the cost of that downtime is also included.

They analyze every element involved and calculate the related costs. This also applies to countermeasures, like applying protective coatings or using corrosion-resistant materials. If we switch to a more corrosion-resistant material, the difference in material costs must be accounted for. Furthermore, if a cathodic protection system is installed, or if routine inspections are carried out to check whether materials like steel are properly maintained (such as checking if they are adequately lubricated), those inspection and maintenance costs are also included.

All countermeasures serve as preventive actions to mitigate the consequences of corrosion. So that is why these things are really required. As I previously mentioned, you can also account for capital expenses if you plan to conduct research and development to effectively eliminate or reduce corrosion. We also need to account for capital expenses related to financing projects aimed at addressing corrosion, such as borrowing costs or potential opportunity costs. This involves examining a specific aspect or subsector and delving deeper to identify the various cost elements associated with that segment.

This is a slightly more complex model known as the input-output economic model. It is a generalized model. It is not only for corrosion. So it is one of the management tools people use, and we try to utilize it to estimate the corrosion cost, which is a very different approach. What they do is try to calculate the GDP in three different universes. What are those? We live in an actual universe where corrosion is occurring.

So they will say Universe One. The second imaginary universe is like heaven; we know that every good thing will happen in heaven. The same is true in this case; there will be no corrosion, and no negative events will affect the materials. So this is an imaginary world that is not there. The third one is a universal tree where we know whatever technologies we have if we incorporate in each and every element than what will come out. So this is another ideal kind of world based on our technologies. It may be that year by year this cost may change, the reason being that new and newer technologies are coming, newer and newer schemes are coming, newer and newer management themes are coming, and how to really manage things in a better manner.

There are three universes, one of which is the actual world. The second one is totally imaginary. The third one pertains to our pursuit of an ideal world. Now, based on that, they do a calculation of the corrosion cost. What is the actual cost of corrosion? In this hypothetical scenario, there should be no corrosion, but in reality, there is corrosion.

Therefore, the GDP of Universe Two will naturally be significantly higher than that of Universe One. The GDP of the second universe is calculated by subtracting the GDP of the first universe. So it will always have a positive value, and that will help the corrosion that is costing this much. Then another thing comes: avoidable corrosion costs because we have technology but are not implementing it. Now why are we not implementing them? One main reason may be that we are not aware of those technologies.

To the best of my knowledge, the scientific community has made significant strides, but these achievements have not yet reached the general public. It has not reached the number of industries; it has not reached the number of small-scale industries, and we know very well that almost 90 percent plus (90%+) industries are small-scale industries, and they have been working in very old technologies. They have not really realized that there are new technologies and their potential. This implies that even if someone is hesitant to invest a small amount of money, we can confidently estimate that you will receive a significant return on your investment.

This means that the return on investment (ROI) will be very high, which is exactly what we aim for. Now, what do we mean by avoidable corrosion cost? We define it as the difference between the GDP of scenario three and scenario one. Naturally, this cost will be slightly lower than the total corrosion cost. Depending on the technology and our progress, the savings could range from 5% to as much as 100%.

Additionally, as we discussed earlier regarding research opportunities, the difference between the GDP of scenario three and scenario two indicates how much further cost can be saved through research and innovation.

In this scenario, the potential for avoidance lies primarily in the management aspect, as we lack technology but have not yet integrated it. So this is our management side, or maybe the awareness and knowledge point. This falls under the realm of research, which is open for exploration. So this could model as such; of course it requires a lot of data and really requires the right numbers, but it is a very good model, a good business model, and then we should implement this kind of model.

Let's begin with a case study that utilizes the Olick method. In the Olick method, we utilize a reference from a 2017 publication, and generally, we provide the data in Yuan or Chinese currency, commonly known as RMB. In this case, the cost is expressed in billions, and our initial focus is solely on inhibitors. Of course there are coatings, surface treatment, corrosion-resistant material, and corrosion inhibitors, which is what we have been showing here, thus preventing oil and electrochemicals. So we may get a number of subclasses in this also, and how much data we have we can do, but this is a class related to preventive methods measures of the corrosion; they have done a coating, they have estimated cost, then surface treatment, and they have estimated cost, corrosion resistant material estimated cost, corrosion inhibitor, they have shown examples over here that volatile material, pickling inhibitors, and others. Maybe this is much more detailed, and overall it only comes in the range of 4.5 to 5.2.

They made an approximation of around 5, which is why it's written here. These are rough estimates meant to help us understand the situation. Looking at the overall proportions, about 66% of the measures used to prevent corrosion are related to coatings. While they may not have accounted for every measure, of those they did, coatings make up 66%.

The second most common measure involves using corrosion-resistant materials, such as replacing steel with copper, aluminum, or ceramics, which accounts for 19.34%. These two categories are the top contributors.
The estimation process is done on a year-by-year basis, with costs related specifically to 2014 in this case. They calculated that 50% of the preventative costs are attributed to coatings. There may also be other types of coatings considered, but 50% of the total cost was attributed to this measure.

That represents 50% of the total cost. This is what has been given in tons. We have estimated the cost in this case to be approximately 703.78 billion RMB, and assigned it a value of 1. So this is an approximation. They discovered information about the production of pants, including the quantity and the approximate cost of each pair. They then allocated 50% of this amount to the cost of coating.

Another one is a surface treatment. Surface treatment is a broad category that includes various methods such as galvanising steel to reduce corrosion, tin plating, electroplating, and the surface design we previously discussed to reduce corrosion. Additionally, it's possible that all other surface modifications are also included in this category. Based on their reference, they estimated the cost of using alternatives to materials like cold-rolled steel. For example, they noted that the cost for surface treatments was approximately 140.8 billion RMB. This is an approximation they quoted in their report.

For corrosion-resistant materials, they considered options like rubber, engineering plastics, corrosion-resistant stainless steel, weathering steel, titanium alloys, and others. The estimated cost of these materials used for engineering purposes came to around 205.581 billion RMB, as mentioned in their findings.

They also noted that the cost for corrosion inhibitors was 5 billion RMB, and for electrochemical methods, the estimated cost was about 6.3 billion RMB. I am not reiterating the details provided in this paper, but rather attempting to delve into the various applications of this methodology. In this case, the total cost, as determined by this measure, amounts to approximately 1063.91. It should be noted that these are direct costs, not indirect ones. We have discussed the indirect corrosion cost, which excludes elements such as compensation for production loss, environmental contamination, casualties, and other damages. So they assume that if this plus N2 is multiplied by 2, it will come out to be something like 2127.8. If you multiply this figure by 1063.91, it will come out. So this is what they estimated in this case, and then overall they try to calculate what the percentage of GDP is; this comes out to be 3.34 percent GDP. In most developed countries, the cost of corrosion is approximately 3%. In most developing countries, the cost of corrosion is approximately 6%, and the main difference between this figure and 3% is due to a lack of awareness and inadequate implementation. We can bridge the gap between developing and developed countries by incorporating existing scientific knowledge.

We must comprehend its overall benefits and consider its potential application across various industries. Now let us take a similar method, the Ulic method, for India. A 2005 publication reveals a similar anti-corrosion technique. Again, here we are not going hard with a holistic manner; we are not going hard with GDP, but trying to do how in an Indian situation it will really be utilized. In this scenario, the cost of paint, varnish, and liquors directly contributes to the coating cost, which has reached approximately $400 million.

This galvanised 57, tin plating or 113, electroplating, nickel base, copper alloy. These are the only metals that have been used, correct? Even internal combustion engines have anti-corrosion treatments. So they have given this as some number, but this is a much, much, much, much lesser compared to overall corrosion cost in India. It's simply a matter of adapting the Ulic method to suit the Indian context. Now if you see again, in this case the major percentage is 26%, while in the Chinese case it was 66% or something like that.

Of course in this case there is much less, while in this case the copper alloy itself, which is acting as a corrosion-resistant material, is much on the higher side (33%). So there is a need to think about applying more and more coating, because those are the 2D element material usages that will be much, much lesser, and then the cost can come down significantly. So this is important for us to understand. These figures, totaling 400 million or 1538 million, are derived from data collected in the 1960s and 61s. However, to adjust to the current price, we naturally need to apply a multiplication factor. This multiplication factor, adjusted for inflation, currently stands at approximately 90.64. Naturally, there will be slight variations in this value over time. It can be 91; it can be 91.5. For this purpose, what has been accounted as a 90.64, and how do we calculate CCA? What is the current Consumer Price Index (CPI)? What is the CPI for a specific year? Then, divide this value by it. We are referring to the overall CPI for that year, specifically 1960, which will provide you with the value shown here.

This figure can be found in this particular case. However, in this case we are trying to figure out from a percentage point of view, and then here this is without a percentage. So what is the value in the maybe suppose this is something like 400 minus 2 or minus 5 and divide by this that will be naturally this number itself will be very high right. So in this case we are not counting 100; if you multiply 100%, then it will come. Now in this situation, particularly when we multiply those factors, this turns out to be instead of 1538; it turns out to be 139404, which is very expensive because of the multiplication, which is almost 100 to multiply with 100.

This cost relates only to the direct material expenses. It doesn't take into account the broader impact of damage or corrosion on society or production costs, which have not been included. We also haven’t considered many common anti-corrosion measures, as this example only covers a portion to demonstrate the method.

To summarize this case study, Rajkopal, the author, conducted this research around 1960. He used this method to calculate the annual cost of corrosion in India, estimating it at 1,538 million rupees. Adjusted for CPI inflation, this would amount to approximately 139,404 crore rupees today. At that time, copper was often used as a countermeasure against corrosion.

These days, we focus more on coatings, and the treatments we used in the 1960s are no longer the same. Technology has advanced significantly, and we now require more updated case studies, especially in India, to compare data and implement more effective measures.

Now, let's talk about the method, comparing it with the China case study. In China, as mentioned, they approach it sector by sector. In their 2017 case study, they considered sectors like infrastructure, manufacturing and public services, water, energy, and transportation. Manufacturing accounted for about 48% of the total cost, given China's prominence in that area. Transportation and energy also had high costs, while infrastructure and water were almost negligible.

In India, however, water would be a major cost factor. To dive deeper into these sectors using the method, expert opinions are crucial. To gather information, they created questionnaires and sent them to different industries. However, many industries were unwilling to share indirect costs, such as compensation for environmental pollution, casualties, or injuries caused by atmospheric contamination.

Afterwards, they collected the direct corrosion cost and plotted it based on their calculations. Now what are the factors in this case? We see infrastructure. What they counted in this case was infrastructure and the cost related to upkeep of the building roads and bridges, which are the main units. In the energy sector, their focus is on electricity, gas, and oil refining operations, all of which directly benefit the energy sector. Regarding transportation, they also consider the railway, aviation, maritime, and automotive sectors. In the water sector, while there are numerous components, the overall cost is relatively low. To the best of my knowledge, pipelines, tanks, water treatment, distribution systems, and wastewater management are more expensive in India.

Coming to the manufacturing, which is on the higher side, they try to look at all the production of the goods and public services considering the effect of the corrosion mainly on the tool, because we know that a tool gets damaged even if it does not get the right finish or dimension. These tools, machinery, and infrastructure are essential for the manufacturing process. So they counted these figures, and then the data they have given is something like this. In this case, you can see that the direct corrosion cost, expressed in billions of RMB, amounts to approximately 62.37 billions for the roads and bridges. Of course, they have also factored in the cost of ports and water, which accounts for a significant portion of the overall cost. Based on their calculations, they determined that the total cost for roads and other infrastructure was 4%. However, the coal mining sector, which is also located in India, accounts for 4.67 percent of the total cost, which is higher than the average.

Corrosion in coal mining is particularly high, accounting for around 4.67% of total corrosion costs. This is mainly due to continuous abrasion and exposure to moisture, which frequently damages equipment. Regular inspections and maintenance are necessary to keep these parts functioning properly, contributing to the high cost.

These figures highlight the sectors most affected by corrosion. For instance, in shipbuilding, the corrosion cost is approximately 9.16%, the highest among sectors, totaling around 58 billion RMB. This high cost is due to the harsh operating conditions, which require significant investment in anti-corrosion measures, repairs, and asset depreciation. The presence of water, chemicals, and constant exposure to marine environments accelerates corrosion in shipbuilding.

This study points to the need for more detailed research into areas like shipbuilding and mining. Future studies, including more experiments, pilot studies, and literature reviews, can provide deeper insights. Understanding these issues will help identify where to focus attention and resources for improvement.

Now, let's move on to India, where we apply the same method. However, we consider this to be a 2011-12 study, and the NSE has provided an economic impact report. Examining this data reveals that the agricultural life sciences account for 6.1 percent of the total cost.

So agriculture is affected severely, around 6%. The two major costs of agriculture are 6.1% and 6%, respectively. The high cost of agriculture can be attributed to the necessity of numerous manufacturing machines for agricultural purposes, as well as the various sectors that fall under agriculture. People argue that agriculture encompasses forestry, fisheries, crop production, livestock, dairy, and poultry. Naturally, the corrosion-related cost primarily refers to the deterioration of infrastructure, irrigation systems, storage systems, and agricultural equipment. We have taken those data into account and used them for this purpose.

Another factor to consider is corrosion in the manufacturing process. Now here it is; they have shown a corrosion in manufacturing of only 5.7%, but as per my knowledge, this is much more intensive, the reason being that in the manufacturing, most of the machines become junk or will not be able to utilize. So losses are much higher, and another thing is that even the tools that get some sort of damage or degrade the quality of the product will not be very good, and then in this stage the quality of the product has to be very high. We talk about the zero defect; it is almost impossible to come up with this kind of output if we do not consider this cost and do not try to minimize it. Water supply is a significant concern in this context, and experts have already discussed water treatment facilities and pipe storage.

Of course, it exists because it is a sector related to the national economy. Management must take a more comprehensive approach, formulating policies to ensure the least amount of corrosion occurs in this sector. So these are the important aspects, and we are trying to illustrate the case study. So the more information goes to the student, and the student can start working on this aspect, because these are the major hurdles in our progress and to help common people. The final method used in this case is the input and output method. This method is highly versatile, not only applicable to corrosion but also applicable to other aspects of the system. This is a general economic model that illustrates how much each sector sells to others in order to meet its requirements.

Essentially, every sector interconnects with the others, and the input output ensures overall equilibrium within those sectors. In summary, we refer to this process as the input-output (IO) method. The IO model illustrates an increase in economic activity across all sectors, which is necessary for achieving net sector production. Therefore, we must consider all sectors when calculating the direct and indirect costs, as well as the specific methods for each sector. Additionally, we must consider the input and output methods for each sector, ensuring a cohesive understanding of how things will operate. Now in this case, particularly a corrosion preventive action, we suppose we required 1 million worth of the plant.

It will display all activities across various sectors, showing where inputs come from, where outputs go, and identifying intermediate stages where corrosion may occur—particularly in our case. In general, this analysis can be applied to identify different areas where system improvements can be made.

The Input-Output (IO) analysis, as mentioned, is a comprehensive method that accounts for both direct and indirect impacts within and across sectors. It’s a valuable approach that should be used. Additionally, we aim to normalize the data to ensure consistency, so that it doesn’t distort comparisons between industries. We understand that one sector can impact another, and this interconnection must be considered.

So we need to do some normalization. Now how it is really useful to the corrosion that is we have written here application of IO to estimate the corrosion cost. The IO investigator will consult a specialist once more; they need an expert's opinion to accurately determine the costs associated with corrosion prevention, repair, or replacement of items. These items can come from various sectors, and we require balancing to ensure that any incorrect data provided by one company can be corrected. That's why maintaining a balance is crucial.

We say that within each industry components that indicate expenditure for the corrosion or the found. So some, maybe even the coating, how much coating expenditure for the pipelines, since in this case then we give some numbers also some fraction. Now suppose I apply a coating to a pipe and the purpose is only to corrosion register; then what I will be doing that I will give a one factor to that. However, if I use a stainless steel pipe, it not only resists corrosion but also plays a role in fracture toughness and hardness. I needed to allocate a portion to the coating, specifically the corrosion resistance, and another portion to the primary strength.

So the purpose will also be divided. And this is very important: if we find whatever features have been added in the system, it is only exclusively for the corrosion point of view, then we can give factor 1; otherwise, the factor will be much lesser. The highest factor is the one; if not, the multiplication factor will be significantly reduced. We will attempt to illustrate this using a specific case study. Before we proceed, I would like to reiterate the workings of this method. We say, which has already been mentioned, that we think about three worlds or three universes.

In the previous slide, I referred to the universe as the worlds 1, 2, and 3. The case study I'm about to present pertains to 1975. Let's consider the year 1935 as world 1, and then imagine a world devoid of corrosion. What will be the cost? In world 3, we can implement the technologies in a cost-effective manner, and nearly everyone practices them. So this is what we have already mentioned: what is the corrosion cost? What is the avoidable cost? Now this is important from that point of view. What we say is that this avoidable corrosion cost is the cost that is amenable to reduction by the most economical and efficient use of recently available corrosion control technologies.

Even though this technology exists, many people are still unaware of it. If they are unaware, it's a failure on the part of the country. It's the responsibility of policymakers to spread awareness and ensure that the technology is implemented. This is crucial in reducing avoidable corrosion costs, which can be as high as 44% or even 50%. This data comes from a case study, which I will reference in the next slide. The direct costs considered in this study include equipment and building replacement, as well as product losses.

Previously, we treated the loss of product as an indirect cost. In this case, the loss of product is a direct cost, while the maintenance costs are also a direct cost due to excess capacity and overdesign. We try to keep some redundant material; instead of one compressor, we keep two compressors to avoid failures that also become costly. Then we have some sort of inhibitor or maybe coating and the metallic coating that also need to be accounted, and then if we are doing some sort of expenditure on engineering or R&D or testing, like we have talked about something like an entity. If we are doing it regularly, that cost also needs to be accounted for, even whatever design modification, material modification, or maybe some sort of purification addition has been done to minimize the corrosion. Even if we want insurance, that must be considered, so the input-output method is detailed.

From a management perspective, it's crucial to make wise decisions, and we also aim to maintain a certain level of inventory, as I've observed several companies with extensive inventory holdings. There are a variety of pulleys, gears, and bearings in stock. Therefore, if an immediate failure occurs, we must also factor in the cost. However, if any additional structural damage remains unaccounted for, the primary outcome of the case study I'll present in the upcoming slide estimates a direct cost of approximately 40.76 billion due to corrosion, a figure we're referring to from 1975. We estimated the avoidable cost to be approximately 18.04 billion. This represents approximately 44% of the total avoidable cost. Despite the existence of the technology, it remains unimplemented.

We argue that the 40% to 44% loss occurs due to a lack of awareness. Our role is to increase awareness about the product, the technologies, and its implementation, enabling better utilization. This chart illustrates the data from the case study for the year 2005. Of course, as I mentioned earlier, the data originates from 1975.

The year in question is 1975, but the calculations indicate that the equivalents are 1984 and 85. So this is a case study. As you can see, there are three columns: column A, column B, and column C. These coefficients indicate the correlation between the fraction and corrosion. We have calculated the corrosion cost based on these factors. The technologies or implementations provided for this purpose also have the potential to prevent the overall avoidable cost.

So this is a universal 2, this is a universe 1, world 1, world 2, and then this is a world 3. For simplicity, we are keeping this as column A, which is followed by column B, column C, column D, and column E. Why are we doing it? Our goal is to determine the relationship. And then, if you look at this C column, like in 18,000, it comes by multiplication.

So A into B will come as a C. Similarly, in this case, A into B will come as a C. This relationship remains intact. Of course you can get more detail from this reference, and this is all happening in this case A, B, and C relation coming to the E, which is avoidable cost.

They have provided a formula, which is : D/B ×C . In this case, if we use D=0.0017, B=0.0083, and C=1250, the calculation would be $\frac{0.0017}{0.0083} \times 1250$. It will approximately be 15. These are approximate values, rounded for simplicity. For example, dividing 17 by 85 gives approximately 0.2, and multiplying this by 1250 results in the same outcome.

So this is now maybe say one-fifth in this case, and it will be done like this whether this 0.2, 1 by 5, into this one here. It will come like this. They mentioned these relationships, and then they said these are the avoidable costs, which is 44%, right? We can easily save 18 billion instead of 40 billion. Now, we've discussed quantification, but the question still remains: how do we establish a measure?

Those techniques have been available for the years, but they have not been implemented. Therefore, corrosion requires specific knowledge about the procedures, working practices, and types of plants. These are known; maybe we have a lot of knowledge already in the literature, but the question comes: how do we implement? Now implementation from a government point will be turning out to be the considering society, but at least in industry these approaches should be accounted.

To address corrosion effectively in the industry, the Corrosion Management System (CMS) framework was developed. The key reasons for this are to manage resources, mitigate risks, train staff, make informed decisions, and continuously improve. Efficient management is essential, and that's why this framework was created.

The framework has two key components: corrosion-specific and management-specific elements. These need to be connected for the system to work. We've already discussed the implementation, inspection, and mitigation strategies for corrosion, as well as lifecycle analysis, ROI, asset criticality, and regulations. From a management perspective, we must also consider financial losses, safety risks, environmental impacts, and system integrity. Corrosion can lead to huge financial losses, but it also impacts safety, the environment, and system reliability.

For industries like oil and gas, a leak could result in major accidents, and chemicals released into the environment are a serious concern. Delays in manufacturing due to machine failure also have significant consequences. Infrastructure, like bridges, is also vulnerable; if they collapse, there could be fatalities. Therefore, CMS must be implemented effectively to reduce corrosion costs, which in India account for about 5.95% of GDP—a large sum that exceeds the entire budget for computer education.

This framework is based on the ISO 31000 standards and integrates with other management frameworks. We approach corrosion with risk-based planning, acknowledging that if corrosion is not accounted for, risks will arise. We need to define the scope of work, assess potential threats, and create corrosion mitigation plans.

Once mitigation plans are in place, we also need to determine how often to monitor them—whether it's occasional checks, regular monitoring, or continuous (24/7). Depending on the risk, we can choose the appropriate approach: a data-driven approach for high-risk situations or a more basic breakdown maintenance approach for lower-risk ones.

From a business and industry perspective, the government should address the broader societal factors, while industries must figure out their specific policies and goals related to corrosion management.

Therefore, it is crucial to establish a dedicated policy for corrosion mitigation and prevention, which should be clearly defined on your website or possibly communicated to all employees. Who is working, what are the objectives, how will it be held accountable, and what are the responsibilities assigned to different individuals in the event of a hazard? Therefore, clearly defining and deciding on these matters can significantly benefit the entire company, as well as the shareholders or other stakeholders involved. So these are the important aspects when it comes to the structure—what is the administration structure? If the rules are defined, duties are defined, and even the report linings are also defined to whom to report in this kind of situation. If we fail to declare or manage these policies effectively, it could lead to the emergence of hazards or even casualties. Even in the planning stage, we've been discussing maintenance, detection, and condition-based monitoring, all of which require comprehensive planning.

The planning process involves identifying and evaluating the corrosion hazard, determining its potential consequences, and deciding the most effective preventive or corrective maintenance method to consider. Of course, to some extent, most of the guidelines have been documented in the ISO 3100 code, and then we treat this complete corrosion detection as a risk-based approach; that is where the ISO 3100 comes into play. The primary focus is on the implementation process, which begins with the creation of policies, followed by administration, planning, and finally, executing the strategy at a comprehensive level. Consider the use of coatings, corrosion inhibitors, cathode protection, material selection, and routine inspection. These are crucial factors to consider.

The next step is to determine who will carry out these tasks, how they will be carried out, and possibly how frequently they will occur. Therefore, we must establish these procedures in writing. Then comes the really record evaluation, and we will be regularly accessing information because when we talk about overall corrosion-related losses, we really require a lot of data. If the data are not documented, then we will not be able to evaluate even the data-driven approach; all the data need to be recorded so that evaluation happens effectively. So, those things are important, and another one we say is continuous improvement. Regardless of the model we employ, be it 1916, 1960, or 2020, it necessitates constant enhancement as technology evolves daily, leading to ever-improving technology.

So, if we start implementing or at least analysing the possible outcome of that, that will be very useful as such. Now, so this is my last slide is what we say concluding remark. We covered surface degradation in the first portion, then environment in the second portion, then we talk about some sort of characterisation techniques, failure analysis, life cycle assessment, and lastly we talk about surface modification and coating, and now we are talking about how to evaluate and how effectively it should be implemented. So, I believe that this course will be very useful to you, and then you will be able to do a lot of innovation or a lot of brainstorming, or we say synaptic techniques, to come up with better and better tools to minimise the corrosion, because the corrosion cost to India is huge and that should be minimized. Thank you for attending this course. Thank you.