Design for Quality, Manufacturing And Assembly
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Lecture – 36
Xerox Producibility Index (XPI)

So, as part of this course on Design for Quality Manufacturing and Assembly, today we will see a method of analysing the assembly difficulty. When we design we have to consider the constraints coming from the manufacturing, we do a the DFM and once these components are fabricated they need to be assemble to create, let us say a sub assembly or the final product. So, the degree of difficulty of doing the assembly either it be manual or be a robotic assembly, needs to be accessed. And based on the indices obtained, one can go ahead with the exercise of redesigning the parts, to enable these of assembly.

So, there are many methods to assess the assembly difficulty. Methods like, the Boothroyd and Dewhurst method and the method that we are going to discuss in this contact lecture that is, the XPI. XPI stands for Xerox Producibility Index. Xerox as you know, is one of the pioneering companies which was making the photocopying machine. And if you would have seen a photocopy in machine, particularly the interior you will see that, it holds several hundreds of parts assembled together. There by the cost of the product is predominantly determined by the assembly costs, along with the part or the component costs.

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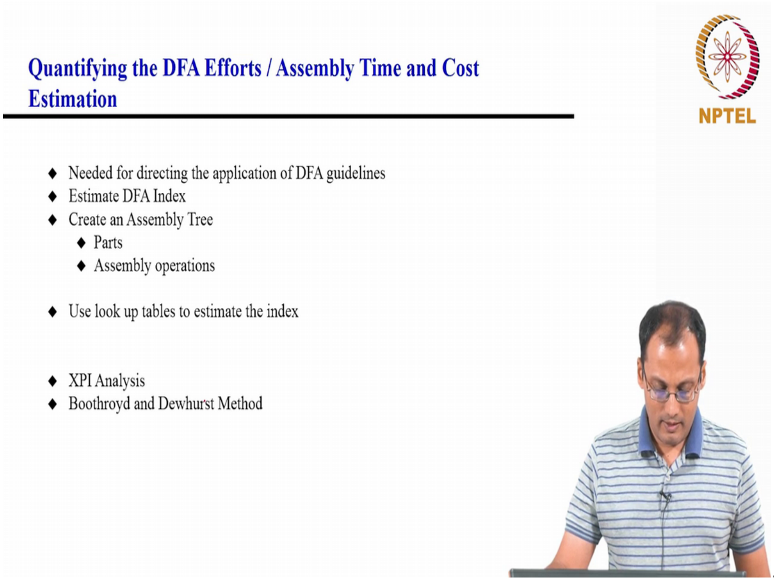

So, the index that can be used for assessing the assembly difficulty could be either the cost, which is essentially in terms of the assembly time. So, most of the methods tries to obtain an estimate for the degree of difficulty, in terms of the assembly time, which can then be converted into caste, based on the labour or based on the automatic assembly line setup cost and the operating cost of the assembly line setup.

So, several DFA guidelines can help in redesigning component to decrease the assembly difficulties, but index which essentially predicts the assembly time is required to objectively evaluate the outcomes of applying the DFA guidelines So, DFA index could be in terms of time. So, in order to do an assembly analysis, we need to understand the assembly steps. We have to hierarchically put these disassembly steps and the associated tools and the attributes like, how is the part being oriented, how is it being grasped, whether some tools are required, so these attributes need to be captured.

So, that we can apply any objective way of assessing the assembly and arriving at the assembly difficulty time so, we generally create what is called as an assembly tree, which puts the assembly operations in hierarchical sequence, along with the assembly attributes.

Then we can use some lookup tables or charts, which can help in assigning the assembly time, associated with each of the operation. So, these times are obtained using work time studies on a statistical basis, on a number of experiments. The average time required to do a particular type of operation, let us say two components needs to be snapped written or two components needs to be assembled using bolt and the nut or it needs to be reverted. So, these operations are repeated and statistical measure is obtained as an estimate of the assembly time. So, these numbers are tabulated and these help us in arriving at the estimated assembly time.

So, look up tables are created, based on such studies So in this lecture, we will primarily see one method, which is the XPI analysis or you know Xerox Producibility Index. There are so other methods like, Boothroyd and Dewhurts method.

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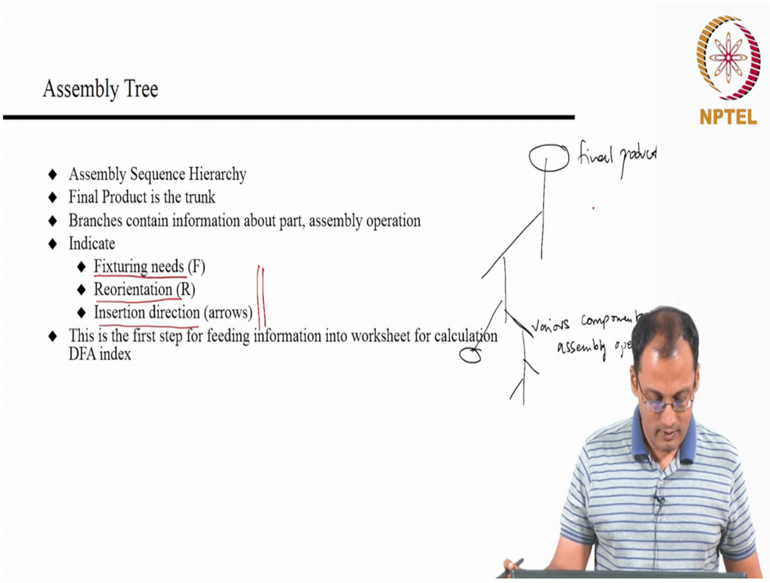

So, let us first see, how an assembly tree is created. I will take some example assembly and describe how an assembly tree is representative of the sequence of assembly operations that will go into the assembly.

The assembly tree is typically an inverted tree, where the trunk is the final product and the leaves and branches essentially represent the components or sub assemblies. So, they come together to form and so forth. So, where the final product is the trunk and these leaves and the branches, they represent various components and assembly operations. So, some of the attributes of assembly, that are indicated in the branches of this assembly tree or whether, there is a requirement for fixturing because, several operations might need the fixtures either to enable the operation to be completed, or for the quality of that assembly operation and repeatability of the assembly operation.

And when we do assemblies, sub assemblies might have to be reoriented, so, that they go into the final assembly. Reorientation is additional step and which if avoided can reduce the assembly time. And also the degree of difficulty typically depends on insertion direction. A top down approach for insertion is typically, the most easily accomplished or the least difficulty operation, but when a component needs to be inserted from a transverse direction or from bottom to top, we can see that there are difficulties associated with visualising, the assembly interface and as well the dexterity and the skill that is required to do those operations.

So, this attributes, affect the degree of difficulty of doing the assembly and there by the time that is required, to do the assembly. So, these are obtained and presented as a assembly tree and the information is taken into a worksheet, which can later we used to compute the assembly time or the DFA index.

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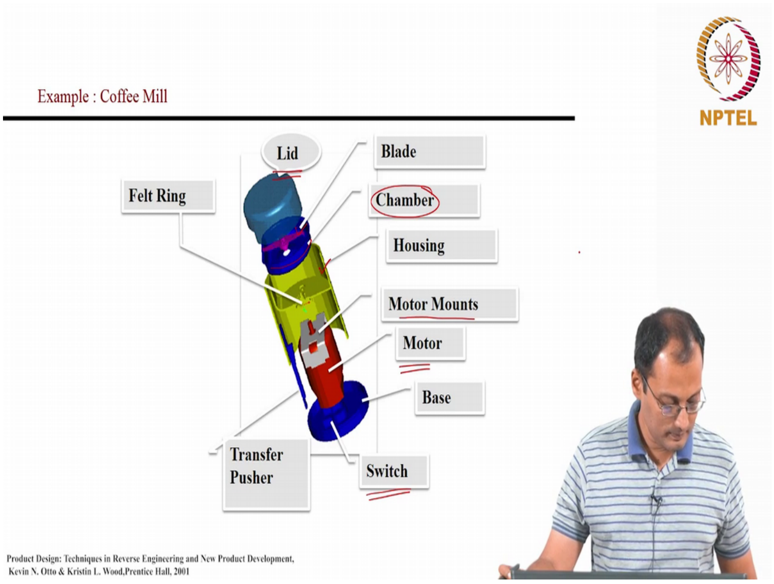

So, let us take one example, a consumer product, here you see a coffee mill. So, it constitutes different parts, this is a cat drawing, so you can see that, there is a motor, which is driving the blade, which mill the coffee to make coffee powder. So, this is an household item, where you can mill the fresh coffee powder from the coffee beans. So, you have the housing this component, you have the blade and the chamber, which is this component and the lid. So, this contains the coffee bean inside the chamber and it is milled. The motor is the prime mover, which moves the blade and it has some electrical connections like, switches and wires. There are some motor mounts, to help properly mount the motor because, that is a moving equipment or the component and it might cause undue vibration, if it is not properly mounted.

So, let us see, how we create an assembly tree for this assembly of this component. And then, analyse using Xerox Producibility Index the assembly difficulty of this component.

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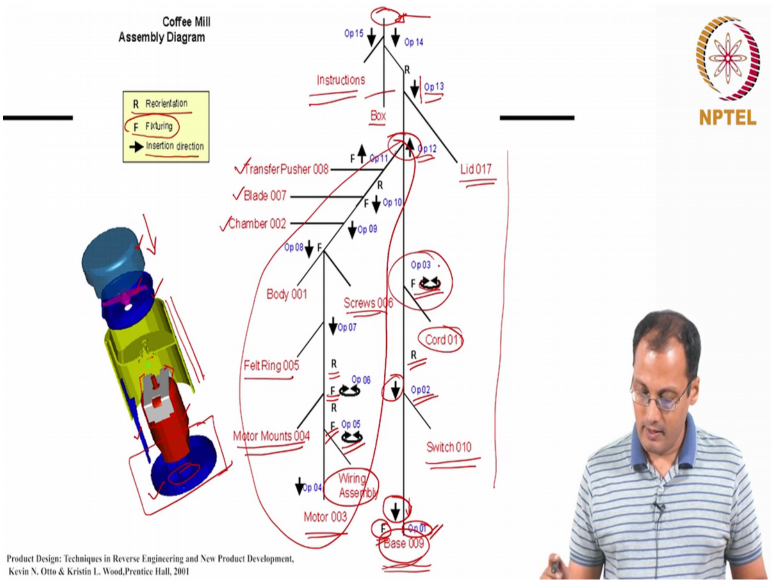

The complete assembly tree for the coffee mill is shown here. As I have informed earlier the tree primarily consist of information pertaining to reorientation if there is any fixturing need and the insertion direction. Insertion directions could be linear motion or sometimes, it might be rotary moment. Like, if I have to assembled something, where I need a rotary moment, I can also mention the requirements. So, as mentioned earlier, the final product is the trunk over here and the various sub assemblies components come as branches, meeting together to form the final trunk.

So, we can start from the bottom; that means, in this inverted tree, we can start from the branches and walk towards the tree, to understand the assembly sequence. So, if I see 2 branches; that means, these 2 subassemblies can be made parallel in two different stations and then, maybe it can be brought in to one station to do the final assembly or if the entire operation is being done in a single station, then it can be done in sequence; either first one of the sub assembly or the branches is completed and then, the other is taken up and finally, these two sub assemblies are brought into create the final assembly.

So, temporarily it can be different; that means, in serious I can do this operations or it can go parallel, by having two different stations and one has to see, how these you know time of assembly has to be matched.

So, let us start with one of the branches. So, typically we have the part numbers, based on some group technology, the company has its own numbering sequence. So, that can be mention to describe the part, so the base part is taken, which is this component, that we seen blue and the switch is attached to the base. So, the base when it is brought in, first needs a fixture, so fixturing is mentioned and it is kept in the fixture in from the top down approach.

So, you see the requirement for fixturing and the assembly operation that is, the insertion direction in this chat, then this which is brought. So, these operations can be named and one can assign the attributes. If I am would like to represent it as a table, I would like to put the assembly sequence or the assembly number and I would like to write down the corresponding attributes for the assembly.

So, once I have put the switch, I will have to do a reorientation, so that I can bring in the cord and attach it to the switch. The cord operation may require it is not a linear operation it might need some rotary operation. So, this completes the sub assembly associated with the base. Parallelly or in a different station, we can do the assembly of the motor, the motor is taken and the wiring assembly is put which, required fixtures and also it might require a rotary or a twisting motion, and the motor mounts are brought.

There is a fixturing requirement to assemble the motor mounts and the motor. And I will have to do a reorientation, to attach the filtering. So, I have the a motor, which has been attached to the motor mounts here, this component that is seen and finally, this goes into the body, which is marked in yellow, this component. So, I might need some screws to put and I may need some fixturing.

So, once this assembly is done, I can then attach the chamber, which is the blue colour and then, the blade and then, the transfer pusher. So, this is the blade and this is the transfer pushers and once this is done, this part of the sub assembly is completed. Finally, I bring in this lid, so the motor mount and the motor assembly is attached to the base using this operation number 12. And finally, I will attach this lid using this operation number 13, I bring the lid in the top down approach and finally, I do a reorientation to put it in a box. And I met at some assembly instructions or manuals associated with this in the carton, which will contain this component and I can then send it to the warehouse or for the product be stored or it can be shifted to the customer to the dealers place.

So, this is an example to illustrate, how the various attributes associated with each assembly operation particularly, the requirement for fixturing whether, there is orientation or change in orientation in between the assembly and the predominant motion, pertaining to the operation; like when I have to do an assembly operation, typically I will have to take the component and insert or place it in to an another component. So, whether that motion is linear or whether, it requires some kind of a rotating motion so, these are captured. So, these attributes are important in computing the assembly difficulty with respect to this method, that we are going to discuss based on the Xerox Producibility Index.

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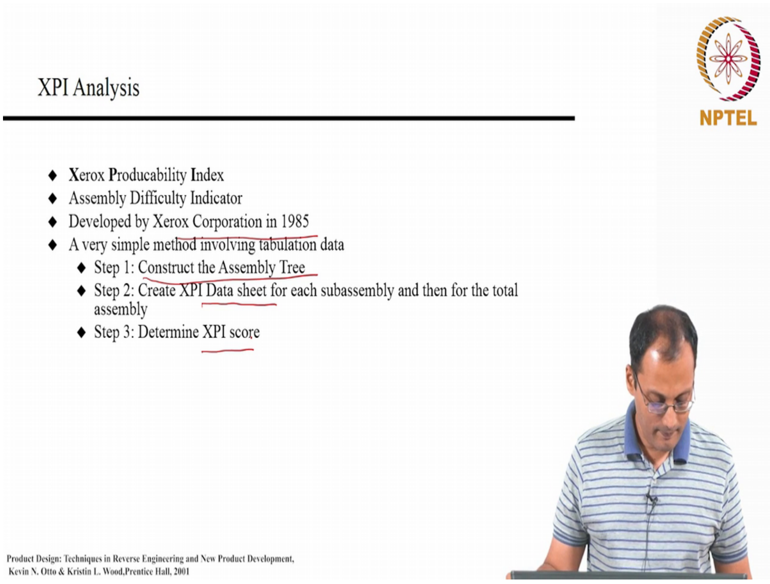

So, we create this assembly difficulty index. Just a small historical note, so developed by the Xerox corporation in 1985, when they were trying to optimise their assembly operations. The first step we have seen, we have created the assembly tree, the data that we have obtained regarding the attributes of assembly we will populate it into a data sheet and then, use the lookup table to determine the XPI score, which is degree of difficulty up to in the assembly.

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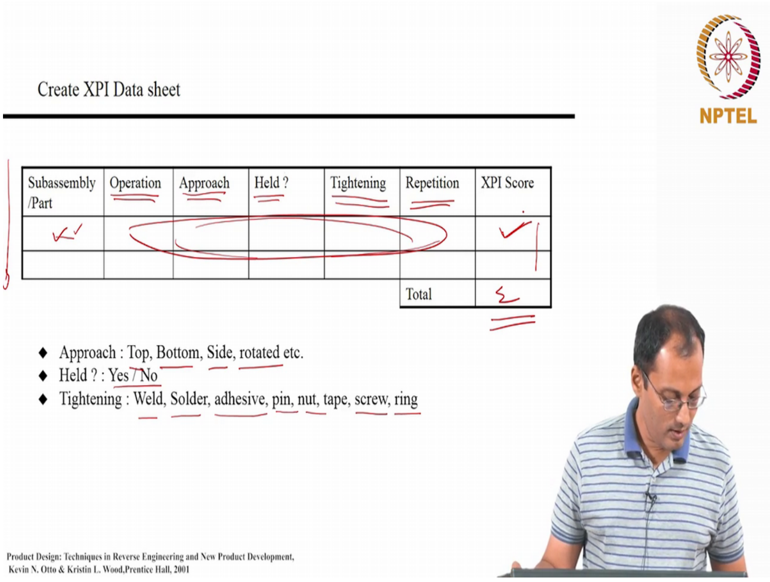

So, the XPI data sheet looks like this. So, we annotate the parts or the sub assemblies the corresponding to each part, we would like to describe the assembly operation. The approach direction, whether the part needs to be held when the assembly is being carried out and what kind of tightening or you know, the operation, fixing operation that needs to be employed and how many times, we are repeating that operation.

The score for this operation is obtained, based on these attributes and it is tabulated. And the total score is computed by summing up and this number is then used to either describe directly the assembly difficulty, or it can be converted into assembly time and that can be used as an indicator for describing the assembly difficulty.

So, the approach can be either top bottom side or rotated that is, how we bring in the component. And in terms of holding, we just describe whether, we need to hold or not. And in terms of tightening, it could be different types of ways of holding it. There is it could be metallurgical operation like, welding or soldering or we can use some adhesives or it could be mechanical like pin nuts, screws or rings and so forth.

So, we describe the nature of holding together the components, which have been brought into the assembly.

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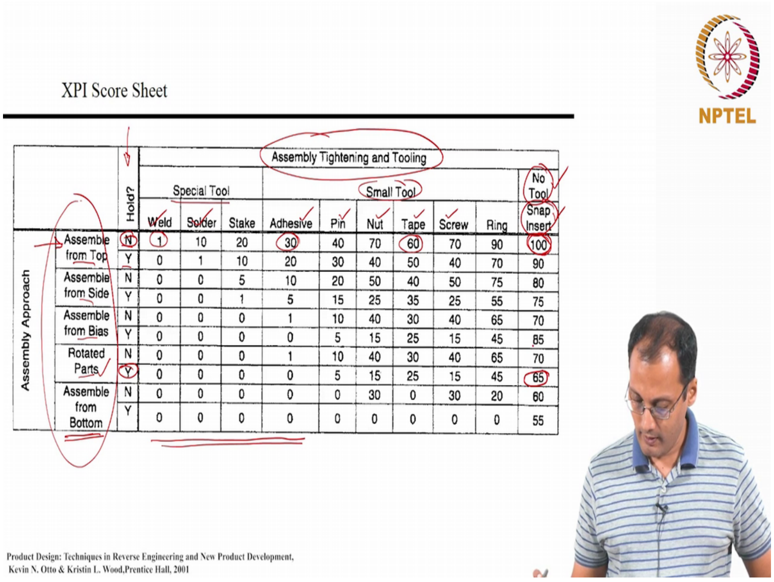

A score sheet is available then, to pick up the difficulty or the XPI score. So, in this table you can see that, on to the rows, we have the assembly approach like, whether we are assembling it from top or from the side, from you know bias or we have rotated parts or we assemble it from the bottom.

And we have the next column, which tells whether, we are holding or not holding this yes or no. And the tightening operation has been classified as special tools like, weld, solder or the small tools like adhesive pins, tapes, screws nuts and so forth. And if we do not have any tool, we can also do assembly without any tools like, we have the snap fit. So, the number 100 essentially means that it has very less assembly difficulty. One can see that, if I do not need any tool that is I do a snap insert and when in when I bring apart from top, assemble from top and I do not need to hold. So, that means, in the first row and if I need to take the last column, that is I do not need any tool, I will get this number 100. So, this is the least difficult assembly operation.

And the assembly score actually goes down all the way to 0, like if I have to do a welding, you can see that, you know it is a very low score because, the difficulty of doing the welding is more as compared to say putting adhesive or putting a tape. So, the lower the numbers, the higher is the difficulty of doing that operation, as described in this table. So, if I have to do some operations from the bottom, we can see can see that, the numbers scores sheets are put as 0, because they are very difficult. So, this table is used, once I prepare the XPI data sheet corresponding to each part when I have captured the attributes, I put this XPI score by pulling up the number from this data sheets and I complete that table to arrive at the total XPI score.

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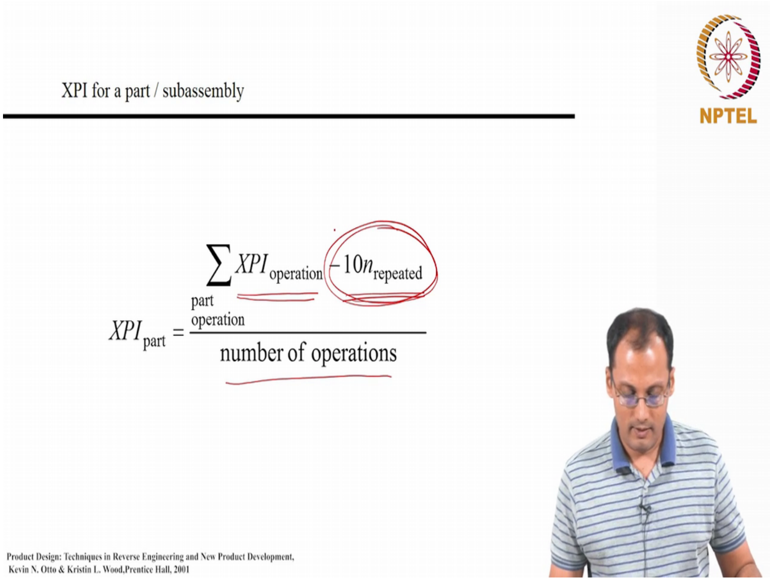

So, for this example we will see how we compute it. And once we have the score, the total XPI is score is obtained and for repeated operations, heuristically a number is a score is reduced, because if, one operation is repeated several times then, the degree of difficulty does not remain the same for each time, when I do the operation successfully. That means, if I have to do 4 screws, 1 after the other, the degree of difficulty does not remains the same. So, to account for that, we just negate. This is the heuristic way of negating the score. So, number of times it is repeated, where reducing and divide it by the number of operations to arrive at an average XPI score for that assembly.

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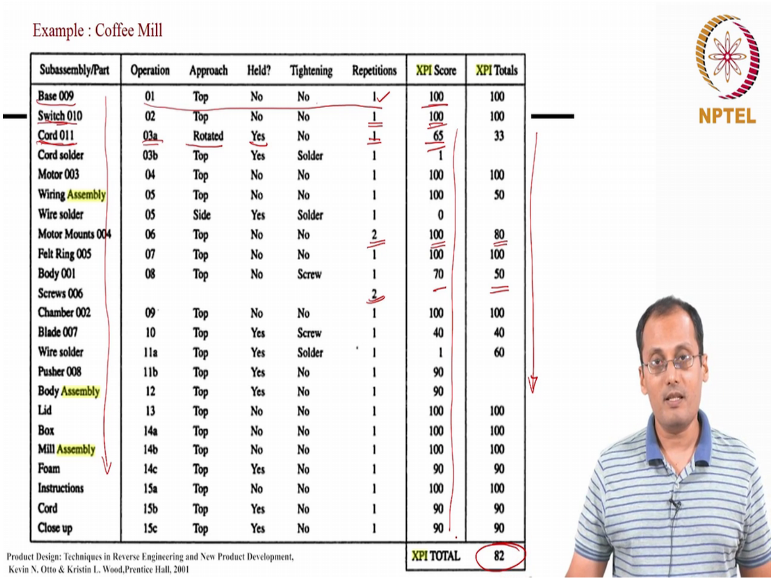

Subassembly/Part	Operation	Approach	Held?	Tightening	Repetitions	XPI Score	XPI Totals
Base 009	01	Top	No	No	1	100	100
Switch 010	02	Top	No	No	1	100	100
Cord 011	03a	Rotated	Yes	No	1	65	33
Cord solder	03b	Top	Yes	Solder	1	1	
Motor 003	04	Top	No	No	1	100	100
Wiring Assembly	05	Top	No	No	1	100	50
Wire solder	05	Side	Yes	Solder	1	0	
Motor Mounts 004	06	Top	No	No	2	100	80
Felt Ring 005	07	Top	No	No	1	100	100
Body 001	08	Top	No	Screw	1	70	50
Screws 006					2		
Chamber 002	09	Top	No	No	1	100	100
Blade 007	10	Top	Yes	Screw	1	40	40
Wire solder	11a	Top	Yes	Solder	1	1	60
Pusher 008	11b	Top	Yes	No	1	90	
Body Assembly	12	Top	Yes	No	1	90	
Lid	13	Top	No	No	1	100	100
Box	14a	Top	No	No	1	100	100
Mill Assembly	14b	Top	No	No	1	100	100
Foam	14c	Top	Yes	No	1	90	90
Instructions	15a	Top	No	No	1	100	100
Cord	15b	Top	Yes	No	1	90	90
Close up	15c	Top	Yes	No	1	90	90
						XPI TOTAL	82

Product Design: Techniques in Reverse Engineering and New Product Development, Kevin N. Otto & Kristin L. Wood, Prentice Hall, 2001

So, this example component the (Refer Time: 26:31) that is the coffee mill, the XPI score sheet looks like this: On to the left we have the components listed in the order, in which we have taken up, say the first operation is associated with the base, we bring the switch and then, we bring in the cord and so forth. So, each of this operation, the attributes are listed So, if we take the base, the number associated with that base operation so is 0 1 which is, what we have given in the assembly tree, if I go back, this is the assembly operation.

So, if I am writing down the attributes of this. So here I am bringing in from top to bottom, I need fixturing and so, these attributes are so, I bring in the part from top to bottom and I do not need to fix anything where, I have a fixture I have just going to place that base in that and I have to repeat the operation only once. So, my assembly score is 100.

The same way for this which, I am bringing from top the direction and I am just repeating the operation once and I am not doing any additional operation, so the score is 100. The cord, if you just taken the third component, which is the put with the with the operation number 3, if you go back to the sheets, which shows the assembly operation this is the operation.

So, it needs a fixture and it needs a rotating motion, so this is captured in the table. This is rotated and you need to hold it down and this also repeated only once. So, if we see the table, the corresponding number corresponding to that is so, you need parts are rotated and you need to hold, you need to hold the component. So, the score is 65, that is what has been written here.

So, like that for each of these components, the assembly score is tabulated. And depending upon the number of times it is being repeated, it is negated n number of operations then, it is a negated like, 10 score is negated. So, let us say if I have to put two screws, I will negate you know 20 from the score, like here we have 2 screws, so from 70 I will negate 20, this is becomes 50. The same here, I have to repeat this operation two times, so from 100, I will negate 2 into 10. So, if you see the 10 into number of times the operation is repeated, that is negative. So, that is what we see in this column and this column is summed up and divided by the total number of operations. So, the average XPI number comes to around 82.

So, if it is 100, actually the score is good, that is the difficulty of assembly is very less and as the scores goes down, the degree of difficulty of assemblies more. So, one can also convert this into time, using say some conversions.

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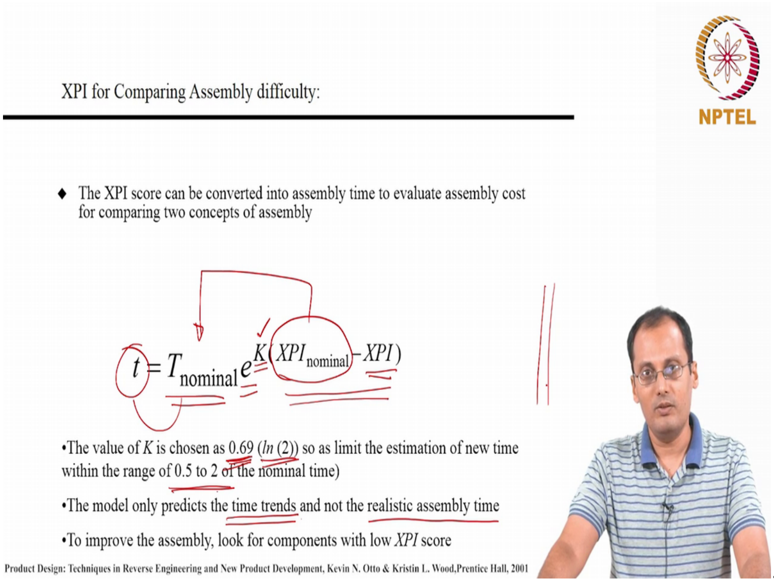

So, we can do an assembly operation and find the time and benchmark that and use that as the standard time. We compute the assembly difficulty for this method, that is XPI indicator and we take these two as the numbers and do a mapping; that means, if there is a change in the assembly score, how far the assembly time can change. So, this is again you an extrapolation and we can use some function to extrapolate this. So, the suggested method is to use an constant K and an exponential function to compare 2 assembly scores and the and arriving at the assembly time.

Let us say this XPI nominal is a benchmark path, which has been assemble and the XPI score corresponding to that part is computed, which is this XPI nominal Corresponding to that, the measured time, experimentally measured time, statistically measured time is T nominal. Then for a change the design, if XPI is the score then, using this equation one can obtain the estimated assembly time. So, one has to use an appropriate constant K and it is suggested because, this K is scaling factor, which needs to be used to convert the difference in this XPI score to help in estimate the difference between the assembly time. So, the value is typically chosen as the log 2 that is, 0. 69.

The idea is that, the deviation is not more than twice the nominal time because, when I try to extrapolate the XPI score to get the assembly time, if I have let say the score becomes more than twice the nominal score then, the extrapolation for the time may not be, the nonlinearity in the relationship cannot be captured beyond that. So, this basically, limits my range of interpolation. So, that the new time is within 0.5, that is half the nominal time to twice the nominal time. So, this is just ensure that the range of estimation is limited to basically half or twice the nominal time. So, you would not need to understand that, it only helps in understanding the trends and it may not exactly determine the assembly time that may be required.

So, if we do a redesign, let us say we do a DFA exercise where, the current assembly is taken up and we try to propose a new assembly. This tool can be used to estimate or give a trend whether, the degree of difficulty will overall degree of difficulty whether, it will increase or decrease, so, that kind of a trend can be obtain and may not be used to actually get the realistic assembly time.

So, there are other methods like the Boothroyd and Dewhurts method, the methods proposed by Munro and associates, where sometimes the predictions are better. But this is one of the earliest atoms in understanding the complexity of doing an assembly and how it can be quantified, using an assembly difficulty index and can help in doing the design for assembly.

Thanks