Product Engineering and Design Thinking
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Module - 05
Embodiment Design and Ecodesign
Lecture - 22
Pugh Method (Concept Selection leading to Embodiment Design)

Welcome back to the course on Product Engineering and Design Thinking. We are continuing on module 5, it is the 2nd lecture of module 5 that is lecture number 22, which as I said in the previous lecture that is lecture number 21 that to have a successful and effective embodiment design, it needs a good input as the correct concept selection or good concept selection or strong concept selection.

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So, one of the concept selection method in continuation with our earlier discussion is the Pugh Method and that we will discuss here and so, first we will see what the session contains.

It talks about Pugh concept selection method, the team role in Pugh method because it is a the design as such is largely product development also largely is a team activity and often though not very comprehensive. But often one would find that the team comprises of people from various functional areas or sections or divisions or departments as we call generally is design department, R and D, the engineering, manufacturing, quality control, purchase, procurement, etcetera.

So, sometimes these are collectively called manufacturing that the process, the quality and the procurement is broadly under manufacturing, but be that as it may. So, that forms a team, the people from those sections forms a team you will understand why the team is required in product development which and also naturally for the concept analysis and those things.

And also, yeah I before I forget to add one important component that is the someone would come from the cost section because the at every stage of the product development cost is a determining factor deciding factor. So, the costing is to be done.

So, one member from that group also forms a part of the team not for every operation the same group will meet maybe, but that is a collective team, but depending on the need the groups are you know groups work or the team particular team or sub teams work on that thing or task groups work on that.

Then we will see how the Pugh evaluation matrix is constructed and then we will take up an example. Example with a ankle rehabilitation robot example taken from literature, we will see how that is performed and the other method also another method again that was developed by Pugh and that will be discussed here.

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Now, as we see as I have already said is a concept evaluation method that uses criteria from the voice of the customer, voice of the customer that is the requirement placed by the customer and that is called voice of the customer.

And so, the criteria are derived from the they are the customer requirements. We have discussed about the criteria earlier. So, I am somewhere it may be if you recall lightweight, somewhere it may be required strength, somewhere it may be aesthetics, somewhere it may be durability, safety, environment, friendliness and whatever the criteria's are and cost is also a major criteria in many cases if not all.

So, now the process this process that we are going to discuss there are two methodologies we will be discussing in few methods two techniques. One is that the comparison both are

comparisons, but it is the you know a three way or five way comparison it is called, I will show what is the three way and five way.

Three way is where only three types of evaluations are made. That is if we are comparing a product a concept a product concept with another concept it has multiple criterion say 15 or 20 criterion. So, for each criterion whether that particular criterion is better or worse or this nearly the same that is the comparison we make and then accordingly we ranked that concept. So, what I just now have said is better or worse or nearly the same.

So, we have I have just talked about three attributes or three grids that is they now it can be it can be the three expression can be expressed in numerically if I say it may be one that is which is substantial a better same or without any change. So, either S or we can put 0 and which is clearly worse or flawed can be put as minus 1 or just minus.

So, either plus minus S or sometimes 0 or plus 1 0 minus 1 whatever the symbols we use that is the three way and for five way similarly sometimes it is used as double plus 0 minus double minus etcetera, but also numerical values are used minus 2, minus 1, 0, 1, 2. So, these are the five and levels of their you know concept conditions compared to a reference or benchmark level which here we called data.

Say if we are saying the in a product suppose if we are saying that plating, they how the electroplating is it a very good quality compared to the existing one then it would be very good, then it would be compared to it is two in a five way system I am talking about.

If we will we will see an example of five way because if we understand five way nicely then three way will be very easy to understand because it is it is a much lesser in number. So, we are taking up another elaborate one that five way one. So, that three way one becomes easier now. So, as we are talking about the electroplating. So, if we are comparing them their coating thickness their durability how long they retained they do not go away easily. So, accordingly suppose you here classify them.

Similarly, if we are checking the strength of a material. So, what is their? Strength if we can find out from there the analysis of their tensile strength and then accordingly, we can if that if the tensile strength is the criteria, then then we put it that way in different grids. If it is very good in strength then it will be 2 if it is moderately good it will be 1 or if it is same it will be 0 if it is worse it will be minus 1 and it is very poor then it will be minus 2.

Now, when I am saying tensile it may be compressive in other cases wherever the compressive load is necessary. Similarly, I am it is not only low rate, it can be any criterion it can be safety criterion, alright. So, it can be you know ergonomic criterion it can be an eco-designed criterion say how much greenhouse gas it is emitting if it is more then it is worse, alright.

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Now, having understood that we first would examine the team role, but now team role I do not have to explain much because just now I have explained to you in short what are the different groups and what they are expected to do.

Here rather the team role I would like to emphasize those things which are the positives from this is that often sometimes the if the criteria was chosen, assigning of the criterion was chosen arbitrarily by any chance, then it gets revealed during the team discussion team meetings.

Members gain insight into the issue and the criteria get better defined through clearer understanding. As it happens in most of the you know team meetings, team discussions, discussions, cross discussion, some debates, at time some criticism and this is called this is this is rather would be should be called critiquing and not so much of criticism it should be critiquing which means that it is a constructive discussion to arrive at a problem solution instead of any personal attack or criticism per se.

So, the discussion also leads to because why I raised this point because we are talking about the team and the team chemistry team role is important where a conducive of atmosphere which is friendly, but professional has to be there. The discussion also leads to symbiotic and synergistic creativity, symbiotic means when one idea fits the other.
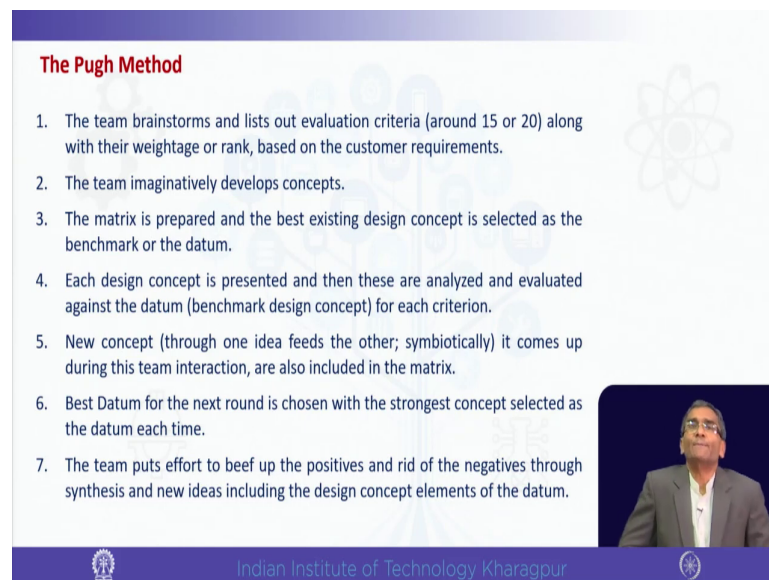
Its interesting I would just like to spend a couple of seconds on this, a few seconds on this that is Tim Brown of IDEO. He pointed out a very nice thing which I think is pertinent to discuss here at least you mention here once that he is called something called innovation quotient and.

He says that the innovation quotient or capability the other words is how one can build on someone else's ideas that is very important capability. So, here that is symbiotic say one idea fits the other. Similarly, synergy I mean one two ideas when I am (Refer Time: 12:52) and improvements are being made it is critiquing synergy and much better idea is evolving. So, and that is through the synthesis of ideas and pitfalls. So, the flaws are attacked together.

So, when that problem is being attacked together the issue is better than then it gets a better remedy or solution. The evolved concepts are better than the primordial ideas which with we started, but then it is getting refined through the discussion otherwise maybe there was certain chance or that certain aspects could have been overlooked. This helps in late modifications or changes often what happens if something gets overlooked now later on it will; obviously, surface and then there will be huge effort and cost and time Spain to rectify those.

So, late changes can be avoided or minimized at least. If it is eliminated that is the best thing. This can actually create a fail-safe product market winning product that is what the role is and interestingly the it has been observed and it is; obviously, expected that team finally, will arrive at a consensus that though there are different opinions or viewpoints, but finally, when the solution is being arrived at everybody shares that solution everybody agrees to execute that solution.

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So, we will explain the method. What is the method? First that we have talked about the team that team brainstorms and lists out evaluation criteria say about 15 or 20 criteria it may be less or more and they are important sort of weightage or rank as we call based on the customer requirements. As customers consider them the important criteria and how important they are etcetera.

Then they creatively or imaginatively the team develops the concepts various concepts I will we will just see what the concepts are. The matrix is prepared and the best existing design concept is selected as the benchmark or datum. We have talked about the benchmark or datum a little while ago. Each design concept is presented and then these are analyzed and evaluated. Each new concept are presented and they are compared with the benchmark

concept or the reference concept or the datum and then whether it is good, bad whether it is 1 or 0 or minus 1 or minus 2 or whatever that is decided.

The new concept as I said that through the feeding or symbiotic approach it often comes up during the team interaction and also included in the matrix. Because matrix started with certain concepts, but through this discussion and concept synthesis idea synthesis if new things come up they are also become another concept which also compared with the data.

The best datum for the next round is chosen with the strongest concept selected as the datum each time. Every time the process is repeated the round is repeated then the best concept so far arrived at is datum and any other concept that is new any other combination is compared with that new or new datum.

The team puts effort to beef up the positives and minimize the negatives through such synthesis of ideas including the design concept elements of the datum. Now, this is the theoretical background or the I would say preparation for the example that we are about to enter into.

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This is the construction of the matrix in short you can see on the left it would be the criteria listed then the datum the reference. Then all the concepts 1, 2, 3, 4, 5, 6 or whatever here there are only four mentioned in this chart. So, suppose four concepts new concepts are being presented by their champions those who are in favour of that concept they are presenting it and others will discuss on it everybody will discuss on it.

The datum is already and presented and against the datum it is being compared. So, that is what the text is written about and then the it is evaluated across the rows and columns horizontally and vertically.

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Now, we will take an example of the Pugh method with a five-way process. So, here a it is the example of ankle rehabilitation robot. What you see? Can see on the right side there is a chart which gives the different component that has gone into the robot and they are say pulley mechanism screw mechanism, 2-way cylinder, DC motor and so and so forth that you can see the stepper motor.

Then if the shape is either circle or square, there are sensors, force sensors, proximity sensors, accelerometers, material there may be aluminium, steel or whatever. So, then there are interfaces and also this talks about I, E, D, A that is the that is the defects or deformities of the ankles which are known as inversion, eversion, dorsiflexion and adduction. So, within certain degrees that you can see that to which extend it twists or bends and accordingly we see the different concepts, here five concepts are presented ABCDE.

So, A through E, five concepts and the criteria chosen here are you can see the mechanism, the actuator, the shape of the platform. As I was saying whether it is circular or it is square, sensors, what is the force sensor or it is the accelerometer or it is proximity sensor or whatever it is.

So, those are listed in the under each concept. Say for example, concept A, it uses pulley mechanism and it uses DC motor and the platform is circular, the sensor is the force sensor, range of joint motion IED, that is it considers inversion, eversion and dorsiflexion and the user interface is there which is common for all and degrees of freedom here is say 4 and material used is aluminium.

So, similarly all these five are presented. Now, after presentation based on the their merits and demerits etcetera after discussing that, the team collectively arrives at a decision whether the it should be ranked as what and that we will see in the next slide. So, this is the example which has been taken from my reference which has been given at the bottom of this slide.

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And what we will see is that in a five way method that we have already mentioned that plus 2 is much better than datum plus 1 is better than datum, 0 is same as datum, minus 1 worse than datum, minus 2 is much worse than datum. So, these are the five ways that we would keep it.

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Pugh Concept Evaluation Matrix (Ankle Rehabilitation Robot)

Total = $\sum_{i=1}^{i=8} Weightage \times Concept\ Design\ Cell$

Measurement Criteria	Weightage	Datum	A	B	C	D	E
Low Cost	5		2	2	1	0	0
Easy Maintenances	10		0	0	0	0	0
Easy to use	10		2	2	2	2	0
Safety	10	Reference Concept	0	0	0	0	0
High back Derivability	10		0	-2	-2	-1	-1
Re-configurable	15		0	1	0	0	1
High Portability	15		0	0	0	-1	-2
Fulfillment of ankle rehabilitation exercise	25		0	-1	0	0	0
Total			30	0	10	5	-15
Rank			1	4	2	3	5

Ex. Total Concept A:
5×2+10×0+10×2+10×0+10×0+15×0+15×0+25×0 = **30**

Concept **A** has ranked first due to the highest total value occurring in that section, so this concept will be preferred.

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And then here for the measurement criteria's what we see are these, what are the measurement criteria, what the customers feel or prefer on what basis they would prefer this model. Here we had seen the constructional mechanisms the table, here what we see is the measurement criteria by the customer that the low cost, the easy maintenance, easy to use, safety, high back, derivability, reconfigurable, high profitability and finally, fulfillment of ankle rehabilitation exercise.

And it is divided into different weighing scale, sub total being 100 and in some this is this is one way of doing another way of doing is taking a scale of 10. So, 1 to 10 that is also is possible. So, keep in mind this is not the only weightage pattern, there are other practices also 1 to 10 also is a scale very commonly used. So, there may be something is may be 5, something may be 2, something may be 10 like that. So, be that as it may.

Now, the datum is the reference concept whatever the concept is and then with that existing that is the existing which is the best. So, far against which the others are being evaluated. So, the datum or the reference concept is presented and against that A, B, C, D, E are compared. Now, say when we are comparing the say for example, let us take one which is the say for example, easy to use, easy to use we see that A through D are very good compared to the datum, but E is the same there is no difference practically.

Maintenance wise if we see they are all equal there is no major difference. Cost wise if you see that D and E does not make any difference in concept, but A, A; A and B are pretty good, C is good alright. So, like that and if we go to the last one that fulfillment of angle rehabilitation exercise where all are equal except B, B is worse not extremely worse, but worse. So, it is minus 1.

Now, having allocated this weights then it is a matter of computation. How do you compute? That is the weightages are multiplied by the value in the cell, in each cell and the sum total under every concept column or concept design column say all sum total of A or sum total of B would give us the results and scores.

Here the best result will be the highest value. So, here if we calculate which the calculation example is given on the right of corner where you can see it is 5 into 2 plus 10 into 0 plus 10 into 2 plus 10 into 0 plus 10 into 0 plus 10 into 0 plus 10 into 0 plus 10 into 0 is equal to 30.

And similarly for B it is 0, for C it is 10, for D is 5, E is minus 15 and so and so forth. Now, looking at this these are the scores of different this thing. Now, it is very easy for you to check which one is the topper and which is the bottomer and what is coming in between.

So, 30 is; obviously, the best, so it is ranked 1, minus 15 is the worst is rank 15 sorry it is ranked 5 and in between those things are ranked as 2, 3 and 4 respectively wherever it is applicable that is self-explanatory and you can understand. So, this is how we can select concept or choose concept which is better and therefore, we will select.

Another model with example: Pugh Method

Criterion	Weight	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Sum of Row	Row average
Plunger Pressure (kg/cm2)	8	3000	2645	1820	2485	1745	11695	2339
Pass over (cm)	7	2230	2380	1970	2575	2500	11655	2330
CG height (cm)	7	34.25	35.05	34.85	34.80	34.40	173	34.65
Back Impact (kg/cm2)	8	590	620	685	570	560	3025	605

Refilling the table with ratios:

New Cell Value = Weight x (Current Cell value- Row average)/ Row average

e.g [Plunger Pressure , Alt 1] = [Plunger Pressure, Weight] x [(Plunger Pressure, Alt 1) – (Plunger Pressure, Row Avg.)]/ [Plunger Pressure, Row Avg.]

8 x (3000- 2339)/2339 = 2.26

Repeat this for all the cells of the table Calculate the sum of columns of every alternate and select the one with maximum value.

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Yet there is another method which is another interesting method that like say it is just earlier it was a binary it was a comparison just relative comparison subjective comparison here is the comparison is a bit quantitative.

Suppose these are the four criterion here that on the left hand side and as I said that the weightages can also be that is why I have kept an example of 1 to 10 scale weight and these are weights are say 8, 7, 7, 8 etcetera it could be different also. Now, what you see there are again say 5 design alternatives. These are criterion are plunger pressure in kg power square centimeter, pass over in centimeter, center of gravity height, CG height is in centimeter back impact is kg per square centimeter etcetera.

Now, the alternative one through this will have different values. Now, the thing is that these values are different. So, something is order of 3000 and something is the order of 34. So, how

those two things can be compared? So, practically it gets normalized through a process that I will discuss just now.

So, what happens is these are the values in the sky blue cells these are the values presented. Now, when we go to the yellow columns first column sum of row there is a summation where basically our objective is not to find the summation, but to find the row average. Summation is just a help that is why it has been listed, but you could write directly to row average absolutely not a problem.

So, the 3000 plus 2645 plus 1820 plus 2485 plus 1745 is equal to 11695, if we divide that by 5 the answer is 239 that is a row average. Now, what is the utility of this row average? The calculation process is shown at the bottom. That is that row average is to be deducted from each of the elements and then that quantity is to be divided by the row average. For example, then let us look at the first case where the for the plunger pressure for alternative 1 it is 3000 and the corresponding row average is 2339.

So, now that value in that cell would become the calculation is shown in red at the bottom 3000 minus 2339 divided by the row average which is 2339 and the value is 2.26. So, it is normalized whether the value is 3000 or 3 lakh or 3 billion, 3 billion or 2 or 1 does not make any difference because we are normalizing enough. So, this is how we will put those values in each of the cells. Let us see the next slide how it is arranged now.

Criterion	Weight	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
Plunger Pressure (kg/cm2)	8	2.26	1.03	-1.78	0.51	-2.03
Pass over (cm)	7	-0.31	0.15	-1.08	0.73	0.51
CG height (cm)	7	-0.12	0.12	0.03	0.03	-0.06
Back Impact (kg/cm2)	8	-0.21	0.23	1.06	-0.48	-0.60
Sum of Columns		1.62	1.53	-1.77	0.79	-2.18

Select the alternate with highest value.
Here, **Alternate 1** is maximum. So, this method will be preferred.

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So, now these values let us say 2.26 which I am going back to the previous slide. So, here at the bottom you see the calculation was 2.26 for the first cell.
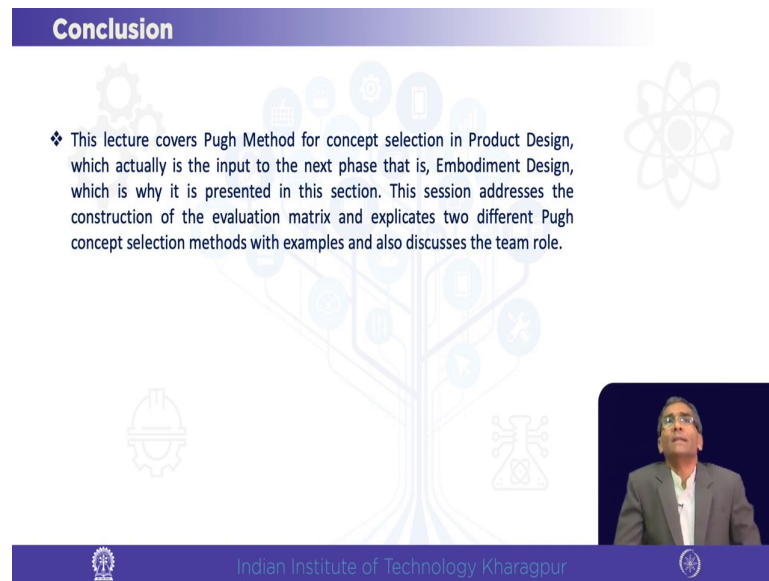
So, similarly it is 2.26 and all other values in the cells have been work out following the same principle. So, once the cells are filled up, then like the earlier method the multiplying the value or the weight and summing it up. So, I have not shown any example because it is already known earlier you have seen. So, basically I would explain 8 into 2.26 plus 7 into minus 0.31 plus 7 into minus 0.12 plus 8 into minus 0.21 if you do that sum total of the first column including all plus minus calculation is 1.62.

So, similarly all the alternatives are multiplied and summed up and these values are presented in the bottom most yellow patch. Hence we see the largest value appears here as 1.62 which is this alternative 1. So, here we conclude that alternative 1 is the maximum.

So, the method is preferred or the best. So, these are the two very important methods in concept selection and if done nicely correctly it will lead to the correct selection for the embodiment design. So, the concept selection plays a very important role in embodiment design, the success in the embodiment design is how the concept appears there as an input. If the best input goes there, best output will come out.

So, though it is also normally discussed along with the concept generation like say morphological design and then Pugh they were very common. But here we are presenting because we wanted to emphasize why the input for embodiment design is important and the concept design is discussed in this section.

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This lecture covers the Pugh method for concept selection in product design which actually is the input to the next phase that is embodiment design which is why it is presented in this section. This session addresses the construction of the matrix and explicates two different Pugh methods Pugh concept selection methods with examples and also discussed team roles.

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The reference is presented here and I thank you very much for attending this session.

Thank you once again.