Systems Engineering
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Lecture - 05
Systems Engineering – Modern Version

Good morning, today we are going to talk about the modern version of systems engineering. As we been seeing how systems engineering and the basic processes has been established and how it has been used by, used for various things. Before getting into detail, we also want to see how systems engineering evolved as a discipline, in which how the processes that were established, how with the advent of technology and all other things, how did the systems engineering processes evolved in.

So today we will discuss mostly about the modern versions of systems engineering in a nutshell and then go from there. I am Dr. Deepu Philip and I am from IIT Kanpur.

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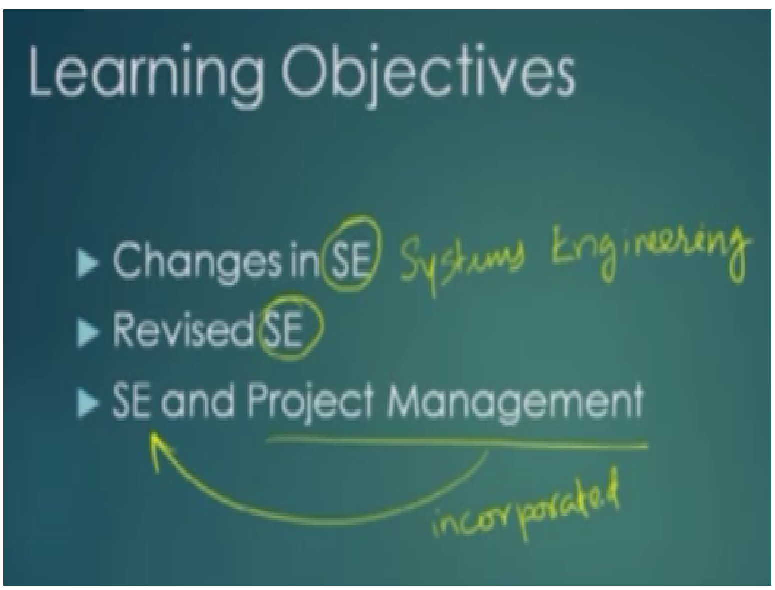

So today's learning objectives are what are the major changes in SE. As you remember SE stands for Systems Engineering throughout this lecture. So whenever you see SE, think about systems engineering. I will specify otherwise. So what are the major changes happened in the field of systems engineering. What are the revisions that happens? How the systems engineering does got revised? And what are the aspects of project management that got incorporated into SE. Some aspects of project management did get incorporated into a systems engineering and what are those. We will see all those things today.

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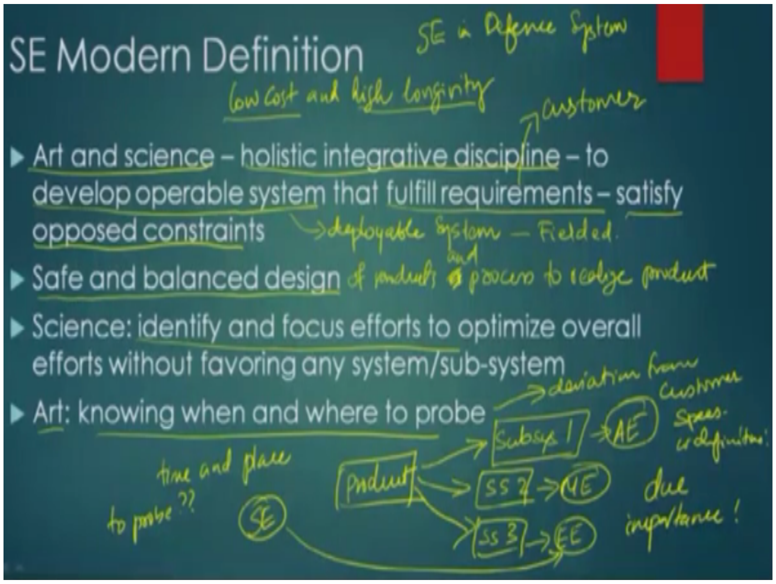

So the system definition, as we said before systems engineering definition earlier, which was a more of an engineering definition and earlier we told that the SE originate, origins of SE are in the defense area. So, from the Department of Defense definitions to a large extent, there is systems engineering started getting wider acceptability across the fields, where our companies, organizations, who are into large projects, (()) (02:10) projects started using systems engineering as a mandatory tool.

The discipline that they integrated into the product, project development or product development, then the definitions evolved and the current definition basically calls it as, people are calling it as art and science. We will talk about why it is not under science. And it is also a holistic integrative discipline. So it looks into all aspects of a product with holistic system. And aim of this discipline is to develop operable system that fulfill the requirements.

So develop operable, operable means systems that are deployable. Operable system equals to deployable systems or what we call as systems that can be fielded. Operable systems that fulfill the requirements. Whose requirements? These requirements are the customer requirements. And in this process, the opposing constraints should also be satisfied. Opposing constraints means the customer might have, might wish things, which might be contradict to each other.

For example, the customer might say low cost and high longevity. Sometimes you might for longevity you would require using better materials or expensive materials. But then the low cost might prevent you from doing that. So these two things can be what we call as an opposing constraints. So how do we realize that? That is actually the satisfaction of the opposing constraints.

In a simple sense, we know that the systems engineering develop and realize end products. But it is an art and science in modern definitions and it is also holistic integrative approach to develop operable systems that fulfill the customer requirements, while satisfying the opposing constraints put forward by the customer. So the aim, final aim of the systems engineering or systems engineering needs to come up with safe and balanced design, design of products or processes.

Processes is to realize the product. Instead of or, we can do and actually. So it is a safe and balanced design of products and processes to realize the product, is what systems engineering, the modern systems engineering talk about. So safety is important and the balanced design is also important. Design is balanced because that is where the art and science comes into picture. You should identify and focus efforts to optimize overall efforts or overall products.

Let us call it as efforts instead of called as products, without favoring any system or a sub system. So, if you have a product and it has five sub systems, so let us think it as this is your product. And you have, let us say instead of five, we will do it as three because it is easy, subsystem one, subsystem two and subsystem three. We have three of them. Then a systems engineer should not, this might be more related to an aerospace engineering.

This could be a mechanical engineering and this could be an electrical engineering, let us say for, this is where the major disciplines are coming into picture and the systems engineering basic engineers, basic trade is, let us say electrical in this one. So he or she should ensure that there is no undue importance with favors being given to electrical engineering because person knows that field better.

All these three areas, the subsystems one, two and three should be given the due importance. That is the most important thing in this. No undue favors into any system or a subsystem that is where the science is, look at things objectively. Or this is second part that is to know when and where to probe, where to look for, where to look to find out there are deviations from the customer requirements, when to look for, so the time and place to probe. Probe for what?

The probing is for deviation, deviation from customer specs or definitions. Earlier we use a term definition. So this is where the art concept comes into picture.

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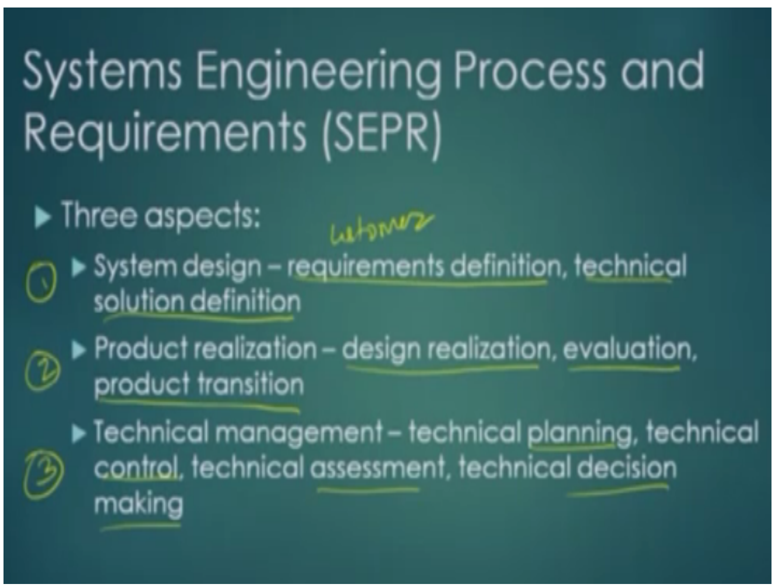

So the modified systems engineering, we talked about systems engineering management as the one in-between. So the SEPR, the Systems Engineering Processes and Requirements, which is again the revised version of simple systems engineering, what we used to call in earlier days. It has three aspects built into it. It is, it has the first one is called as a system design. System design is primarily relating to the defining the requirements.

So the requirement definitions is, this is the customer requirement definition. Then also you from where you are talking about the technical solution definition. What technical solution can be provided to meet the customer requirements, is part of the systems design. So this is the aspect number one. The aspect number two that regard is the realization of the product, where product realization, which translates the technical solution definitions.

Of whatever it is evolved out of the system design is realized into a design, from the design, the designs are evaluated and then the designs are translated out, transitioned into products. So in this case, you are creating a product from the design requirements, which is the second phase. Then the third phase is actually the technical management, where the technical planning, the planning, the control, the assessment and the decision making aspects, which are technical in nature, which are related to the project or the product development or completed in conjunction with both one and two.

So these are the three aspects of the systems engineering process and requirements. We will see all of them in detail and find out how one system integrates with the other.

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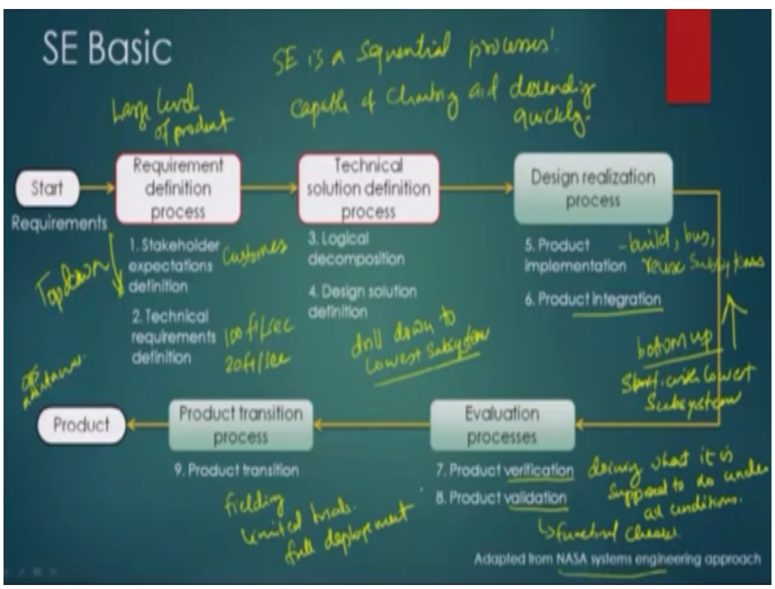

So we look at this, this flow chart basically, it is adopted from the NASA systems engineering approach, written out right here. I would recommend you students to read that book or the handbook that NASA has published on this. It is quite informative. This basic flowchart that you see, when you start with the requirement definition process, where you have discussions with the customer, get the requirements.

There will be opposing constraints and other things. But you define the requirements, which in the earlier slides, we actually called it as base lining. So that aspects comes here pretty much. Technical solution and definition process is, where you evolve the technical solution definition out of the customer requirements. So it is kind of a sequential process. Remember earlier, we said that systems engineering SE is a sequential process. So the sequentiality is shown here.

From the technical solution definitions, we realize the design. Design of the product is realized out of that. And then once the design is realized, the design is evaluated and the evaluation gets translated to a product. So you develop a processes to actually build the product. And then the product gets developed and it is fielded and other things happens. Then we talked about the lifecycle after that.

So after the product, it is the lifecycle, the operations, maintenance, all those aspects comes out of this. So, each one of them have some specific sub steps belong to it. We will go through each one of them. So the start is the requirements aspect or a place where you identify an unmet need. So if it is like, let us say for example, if we take the example of NASA. NASA decides how we will send somebody to Pluto.

So that is where the requirement is to travel to far, the farthest planet in the solar system. That could be thought about as a requirement. Once the requirement comes in, there are multiple meetings that happens. And then the first thing that happens is called the Stakeholder expectations definitions. The stakeholder or you can call it as the customer.

Whatever the customer expect out of this product is being defined, is actually crystallized out into a tangible definition, which can be used later to identify whether the product developed is matching this stakeholder’s expectation. Once the stakeholders’ expectations are documented well, the technical requirements are defined out. The technical requirements in this regard is about the customer might say things in a very vague manner, might not be able to specify it in the technical terms.

So that needs to be created. For example, if you are in the process of building an aircraft and you are in the, you are in discussion with an airline agency and then the airline agency will, might present, present things in different way. Let us say for example, the airline is a regional transport operator, like for example, if you take it in India, Indian - let us talk about a low cost air carrier called indigo, which is a point to point system, they do not have a hub and a spoke model.

So they go from, they do multiple hops of an aircraft. So they might be flying from Lucknow airport to Bangalore, via Delhi, Delhi to Bombay, Bombay to Hyderabad and Hyderabad to Bangalore. So they will have multiple hops in between. So these are all short flights of ranging from one to two hours. So the customer might come up with the situation that says that the aircraft should be capable of climbing and descending quickly.

This is what the customer might say. But the technical requirement might say the rate of climb of, let us say somebody says at a level of, let us say hundred feet per second or something like this or at a, you are losing an altitude at the rate of twenty feet per second or something like this. So I will, I am just giving random numbers, not really actual values. But these are called as a technical requirement.

So the customer expectations gets translated to technical requirements, where those are tangible, measureable items that would satisfy the customer expectations. Once that is done, I told you the technical solutions definition process, it has two aspects to it, logical decomposition and design solutions. So logical decomposition is you start decomposing the technical things, grouping them together into subsystems because a large complex system would have definitely multiple subsystems and it is easy to deal with small subsystems.

So the question usually is how do you eat an elephant. The answer is one bite at a time. So by building into logical subgroups, you will be able to manage the project better or manage the customer expectations better. And once the logical decomposition happens, then you develop a design solution to meet the logical decomposed technical requirements. So like for example, somebody might say that after the takeoff and the aircraft reaching a height, reasonable height.

It should fly by itself. So the reasonable height, let us say for us, for the time being is defined as ten thousand feet. So then somebody says, ok an altitude check system and an autopilot engagement that should be one module. So that somebody will focus and developing it and as soon as the altimeter reads ten thousand feet, autopilot comes on and says ok I am automatically engaging and continues the process.

So that subsystem might be the grouping of two things of the customer requirements and developing a subsystem to realize that. So there are so many subsystems like this, innumerable subsystems in any complex products. So once these twos, the requirement definition process and technical solution definition process comes in, it drills down from the major requirements, we will discuss this later, of product and here you drill down to lowest subsystem that is the idea.

By the time this fourth step is done, you should have all the subsystems that are necessary new at system, with you to build the system. Then comes the next aspect. From the design solution definitions, you start to realize the design or you start to make them. So the product implementation here is, build or buy or reuse the subsystems, so starting to implement the designs solutions.

So the design solutions definition gets translated into product implementation. If the subsystem is not available anywhere in the world, you build it. If it is available, you buy it. If it is not available, but there is an all system available, which can be furbished or it is already available in some other form, you get it and reuse it. Then what you do is, the subsystems start to get integrate with each other.

This is where your interfaces, integrations, check that both, when you integrate to subsystems together, they are working as expected, so here you are actually going from the bottom up. This was a top down approach. The requirements flow from the top, all the way down to the lowest level of the subsystem. Here bottom up, you start from the, start with lowest subsystem and then you start building up all the way to the, you start integrating the product.

You start building the final product. So it is a bottom up, it goes the other way. We will see this in more detail in the following slides. Then comes the evaluation process. Once the products are integrated, you do verification and invalidation. So the verification, we will talk about later. But what verification is in the sense is, it is doing what it is supposed to do under all conditions. Verify that you have built what you supposed to build.

And validate is that it is capable of doing all the functions that you want it to do. So, here is the functional check also coming into picture. Once this is done, then comes the product transition, where what happens is, you validate and verify the subassemblies, then you keep on doing this and then the product gets transitioned into what we call as the final assembly and the fielding. So here, fielding limited trails, all those kind of things goes into as part of this.

You transition the product into full deployment. All these aspects comes out as part of the product transition process. So we will kind of look at this in a little bit of more holistic view in the next slide.

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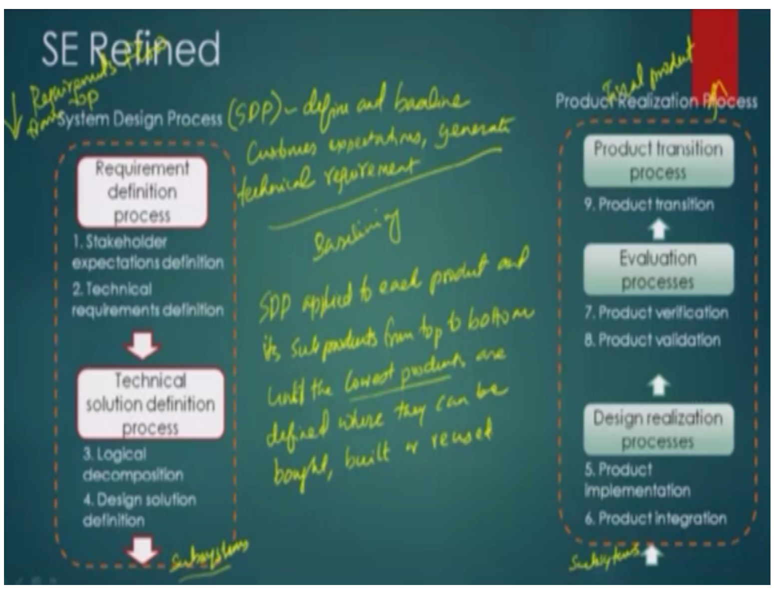

So as I said earlier, these are the nine things that we saw earlier, represented in a different fashion. And in this you can actually see that, the requirements, it is, as I told you earlier, you can think about this as the requirements, flow from top. It is coming down this way. And at the bottom, you have what we call as the lowest level subsystems. So the requirement definition process, from where the technical solution processes happens and at the lowest level you get what we call as the subsystems.

All sub systems of the major system are available right here. Then from there with the sub systems you start and then you integrate into the final product. So the floor here is the upwards, it goes from the sub systems all the way to the top. So we group them, these two the first group is called as a system design process SDP, very commonly known as SDP.

So we will first talk about this. SDP it is the purpose is to define and baseline. The Id is this define and baseline. Baseline the customer specification or customer expectations with that and then you basically generate the technical requirements. So the earlier aspect all of this is, in all the Systems Engineering model we used to call all of these as base lining. So that same base lining process is further established or further expanded into a much more tractable reasonable steps.

So this is and you should also think that this processes, the processes in the system design process. SDP processes, they are applied to each product and its sub products from top to bottom until the lowest products are defined, where they can be bought, built or reused. See, define it to a point, where the lowest products are identified and then the sub systems are identified, which can be built or bought or they can be reused.

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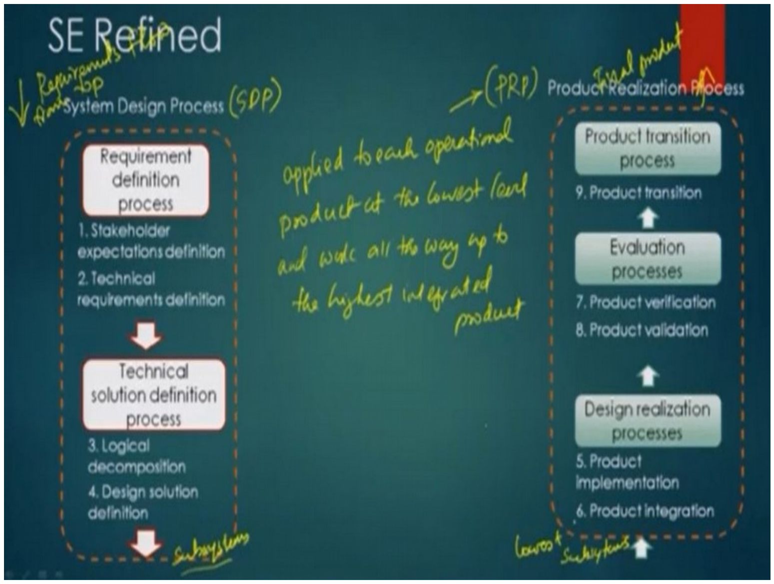

And then we will just go through the other definitions because there are more things to come in the middle, that is why erasing them, otherwise it will look extremely crowded. So the SDP we discussed what it is, then whereas the PRP the Product Realization Process commonly called as PRP. It is applied to each operational product, so if you define about this, it is applied to each operational product at the lowest level and work all the way up to the highest integrated product.

So you start from the Sub systems or the lowest level. So here we are talking about the lowest Sub system and you start work up all the way until you reach the final highest integrated product.

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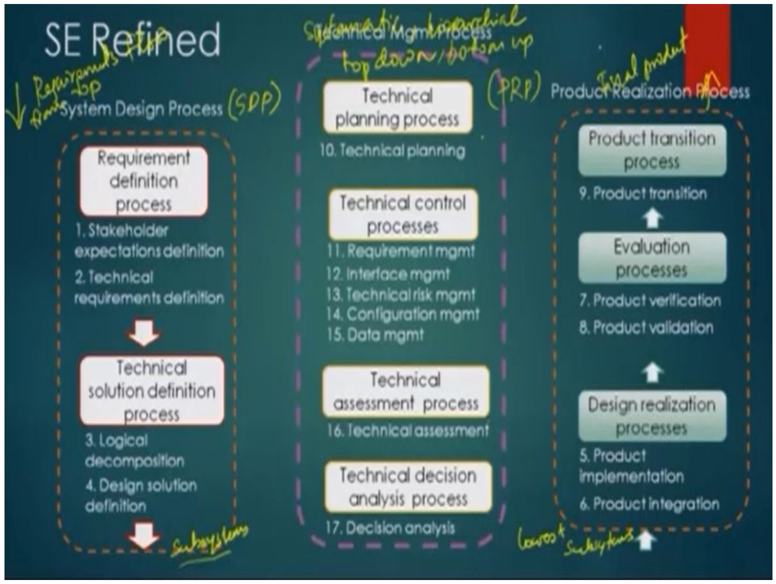

So the PRP process and the SDP process is basically little bit redefined systems engineering approach. The early systems engineering approach done little bit more nicer fashion. So this meets the earlier aspects it is systematic, hierarchical, top down. So top down is here and here we actually have a bottom up. So we will add bottom up also as part of the process. So when you have this, then there is something in between, there is some technical stuff comes in between.

So there are four aspects to this, which is the Technical Planning Process, The Technical Control Process, The Technical Assessment Process and The Technical Decision Analysis Process, so the planning, the controlling, the assessment and the decision making aspects, which we mentioned earlier gets sandwiched between the SDP and PRP, which has the technical planning process basically is a Technical planning, however we are conducting all the planning related to the technology required to meet the, realize the product that is done there.

So if you see the sequence in which 1, 2, 3, 4, 5, 6, 7, 8, 9 happens basically says, ok this is the order in which we do and once in between the same 10, 10 does not mean that it happens after 9 but what I am saying is technical planning is something there happens along when you are doing the top down and the bottom up approach. So, then once the technical planning is done then you have the Requirement management, Interface management, the MGMT stands for management, risk management, configuration management and data management.

We have seen all these things earlier in the systems engineering process management bubble of the previous design. It is much more crystallized and put it into different bucket in this case, pretty much what it is. And then there is a technical assessment and then the decision analysis. So all these things put together is called as the Technical Management Process. I have kind of written something on the top of it so we will go back to the previous slide.

So it is a top-down, that the technical management process kind of runs in parallel or kind of gets sandwiched in between the PRP and SDP, where PRP starts from requirements all the way to sub systems, it drills down to the subsystems, whereas the PRP start from the lowest level of sub systems definitions and keep on building and realizing them until you reach the final integrated product. So the technical Management process, when we talked about it, so what is it used for?

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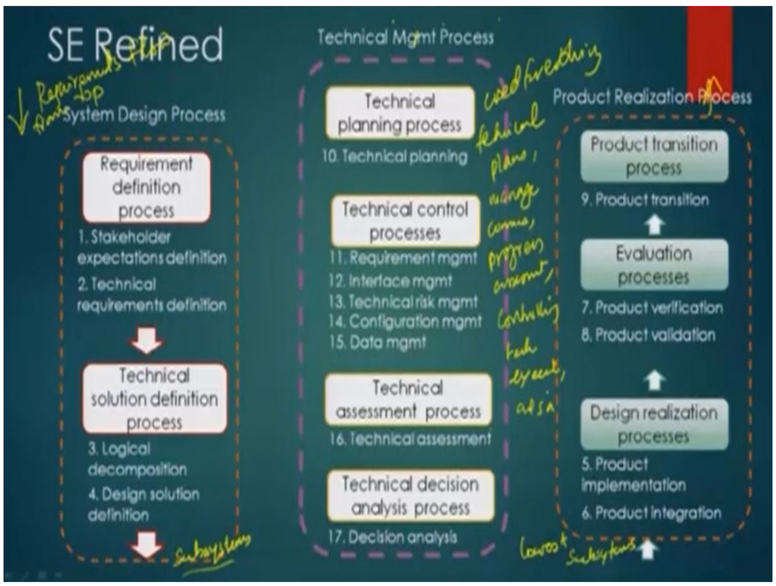

So the Technical Management process it is used to establish and evolve technical plans for the project. So, used for evolving technical plans for the project and then it is also used to manage Communications between the interfaces, then the progress assessment, then we talk about controlling the technical execution, and so on, So this is basically looks into the both the processes simultaneously.

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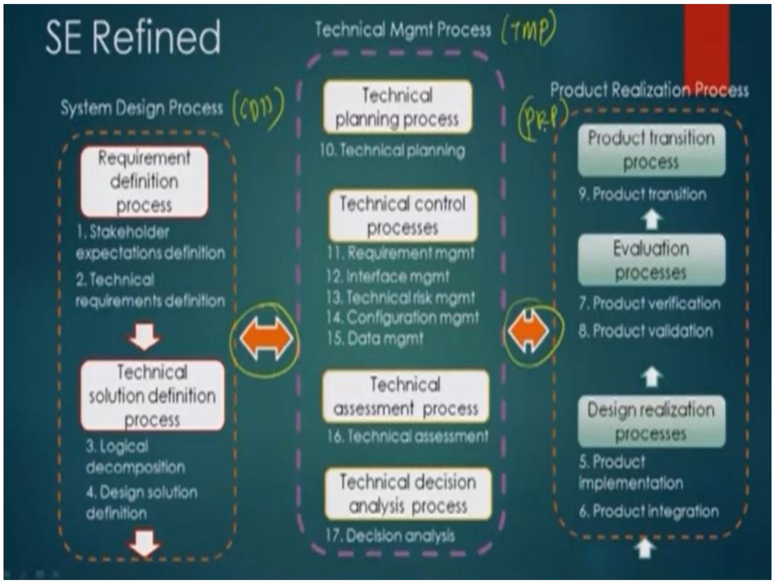

So if you want to see that in a larger scale this is what it is. It interfaces with both, these two arrow marks here suggest that the interfacing happens between both of them. So the planning, the control, the communications, the decision making, the assessment and progress analysis all those kind of things, which are required in different stages gets done.

So the tools and techniques that are required to realize this gets bucketed into what we call as the Technical Management process which is called as the TMP. So the SDP is a System design process and the PRP is a Product realization process. So it is SDP, TMP, PRP interfaced between each other realizes the refined systems engineering or later at the current version of systems engineering.

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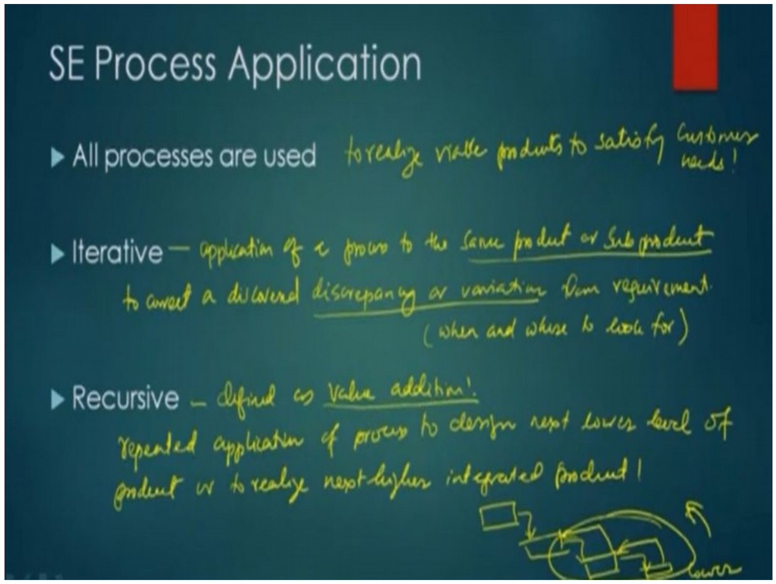

So now we talk about Systems engineering process application. All processes are used and we told that this is used to realize products. So systems engineering is used to realize viable product viable products to satisfy customer needs, you already seen this. The process is iterative and the process is recursive. We mentioned that also. This is also an iterative and recursive process. So let us define iterative and recursive little bit more clearly here.

So iterative is defined as it is the application of a process to the same product or sub product to correct a discovered discrepancy or variation from requirement. So what we talking here is application of the process is the same product. So the application is to same product or sub product to correct a discovered discrepancy or variation from the requirement. So you found out some discrepancy or variation and you want to correct that, so the variation is in such a way that it does not needs a customer requirement, so trying to correct that.

So this is when, this is also about when and where to look for which we talked about as the art of these systems engineering. So Iterative application is typically about applying the process to the same product, you apply the process iteratively again and again until the variation or discrepancy is corrected. The recursive on the other hand it is defined, many people called as it is defined as value addition. So, how is this value addition being added?

This is always a big question. So the value addition kind of happens by this. It is the repeated application of a process to design next lower level of product or lower layer of product or to realize next higher integrated product. So here you are doing is, you are not saying with same sub product. You start with the sub product, you drill it down you go to the next sub product drill it down you go to the next sub product, and you keep on doing this.

There is one option so you recursively in this case you are going down, you are going to a lower level or you can either do this, you can integrate them to a higher level and with these integrations you recur it up, you are moving up, So this is the iterative and recursive aspects that we discussed briefly touched upon yesterday.

So in an iteration, repeating again it is applied to the same product or sub product to solve a discrepancy or variation whereas recursive is applied the same process keeps on getting applied to the next lower level of the product or the sub product or next higher level gets integrated to the next higher level to increase the aim is to realize value addition.

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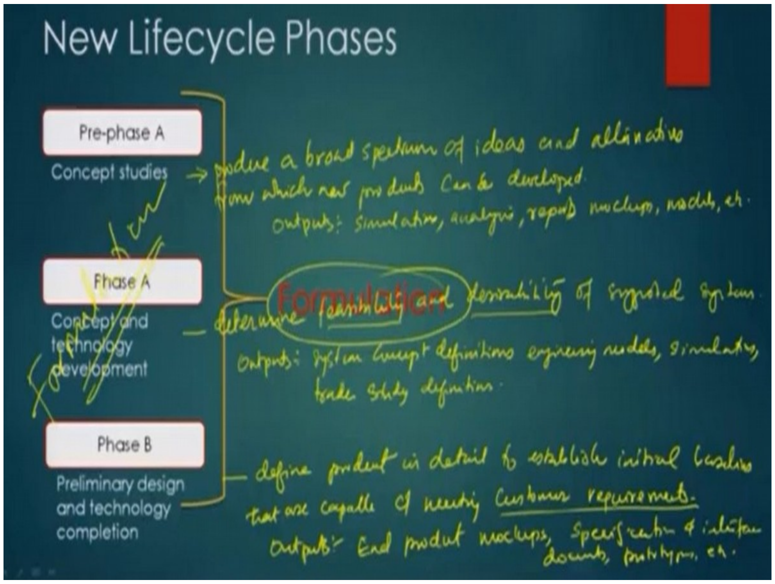

Since we saw the systems Engineering has modified and changed by itself. Let us talk about the changes that happens in the life cycle of the product as well. So the life cycle of the product we can define it in the form of the three phases first and then we will talk about the other parts little bit later down the road. So the first thing that we talked about is the Pre - Phase A and Phase A and Phase B. So what are those? So the Pre - Phase A is typically concept studies and Phase A is concept and technology development and Phase B is the preliminary design and Technology Completion.

So, let us talk about what each one of these aspects are. So the concept studies can be defined as, it is used to produce a broad spectrum of ideas and alternatives, from which new products can be developed. So, it is a broad spectrum of ideas and alternatives from which we can design and develop new products. So the typical output of this phase outputs include simulations, analysis, reports, mockups, models etc.

These are not really working models or anything. But these are generally providing an idea of ok here is the broad spectrum of ideas from which we can realize a product or a new process that can realize or meet that requirement. The second part, the phase A is a concept and technology development as the name says it is actually, the main aim is to determine feasibility and desirability of suggested systems. So here we determine whether this feasible and desirable is it needed?

The outputs of this typically or in the form of what we call as again you know is the system concept definitions, the baselines in the form of Engineering models could be simulations or it could be trade study definitions. So, here you are basically evaluating is it feasible and is it desirable to proceed with the any of the ideas that were developed as the part of Concept studies. And the answer is yes, you have done everything then you go to the next phase which is the phase B.

The phase B is a preliminary design and Technology completion. So the usage of this is to define product in detail to establish initial baselines that are capable of meeting customer requirements. So here you baseline the product in the technical capabilities, that means the customer requirements. So you come up with ideas, check the feasibility and desirability from there you do with this.

The typical outputs of this is in the form of end product mockups, it's also the specification and interface documents, prototypes etc. So this, all these 3 things put together is currently called as the formulation phase. This all of them together gives you the formulation aspect, the phase of the life cycle of the product.

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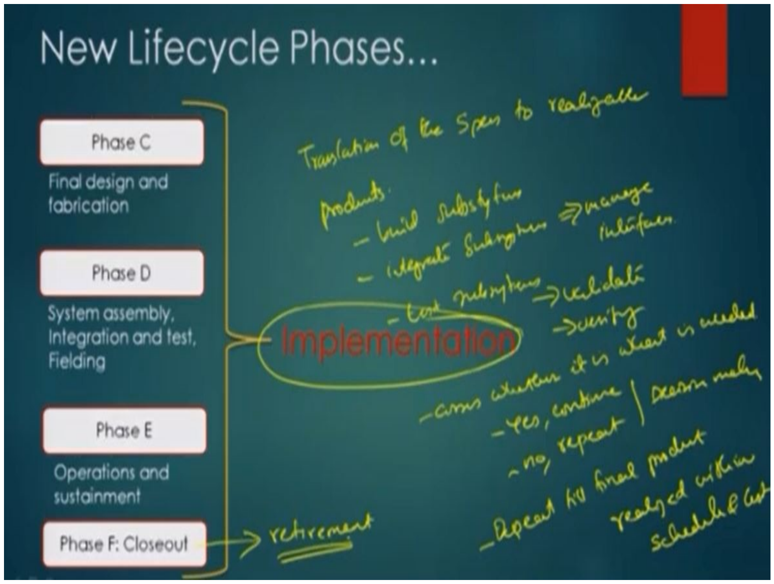

Then comes the phase C, Phase D and Phase E and we will see what they are. So the phase C is the final design and fabrication, so in the first part of the life cycle you came up with the documents and specifications. Now, we start the final design and fabrication, now this is the bottom up going on and then you do the assembling, integration and test which is Phase D and Phase E is the operations and sustainment and then comes the phase F which is a close out, all of these put together becomes the implementation.

So this is where the translation of the specs to realizable products. So you build sub systems, integrate sub systems in this process you manage interfaces and test sub systems, here you do validate and verify once sub systems are done then you access whether it is, what is needed if the answer is yes, continue, it is no, repeat. So here is your decision making and then you keep on repeating this until the final product is built.

So repeat till final product realized with in schedule and cost. So this is the Implementation side of where you translating the designed documents into a realizable product. And the final phase close out is where you are kind of what we told earlier like the retirement of the product, where you are disposing it kind of switching it and completing it. So with this we will complete today's presentation and we will look into each one of these aspects from both the traditional as well as the modern angle in the following lectures to come. Thank you.