Systems Engineering
Prof. Deepu Philip
Department of Industrial & Management Engineering
Indian Institute of Technology -- Kanpur

Lecture – 08
Systems View Point

Good Evening. Today we are in the eighth lecture of the systems engineering course. And today's lecture title is systems view point and I am Dr. Deepu Philip from IIT Kanpur. And we need to go through the systems view point today because it is also a recap what we have done so far and it is also it is precursor for introducing you guys to the different tools of systems engineering.

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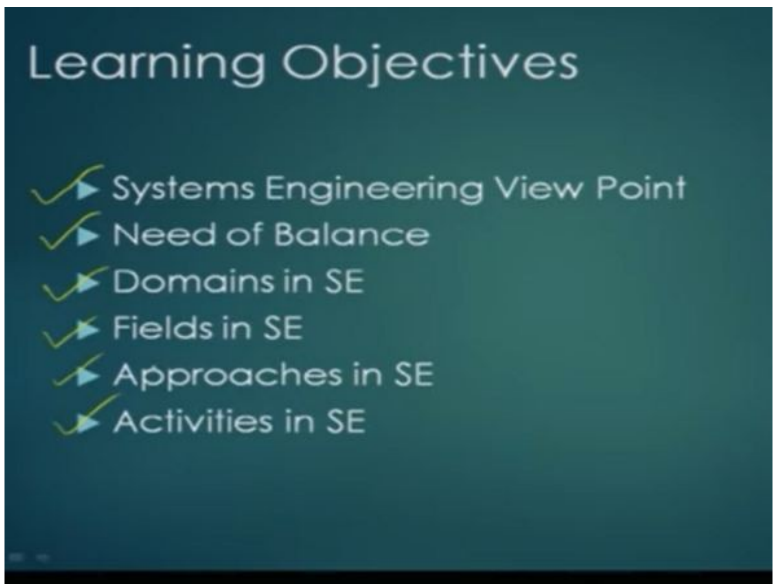

Today's learning objectives are involved the major following points. The systems engineering view point is what we will discuss as the first thing. Then we will also talk about the need of the balance or why balance is an important activity of the systems engineering. We will discuss about the domains of the systems engineering and then the various fields in systems engineering. Then we will see what type of approaches we follow in systems engineering.

And some of the activities of systems engineering and we will try to combine all of these into the systems life cycle module.

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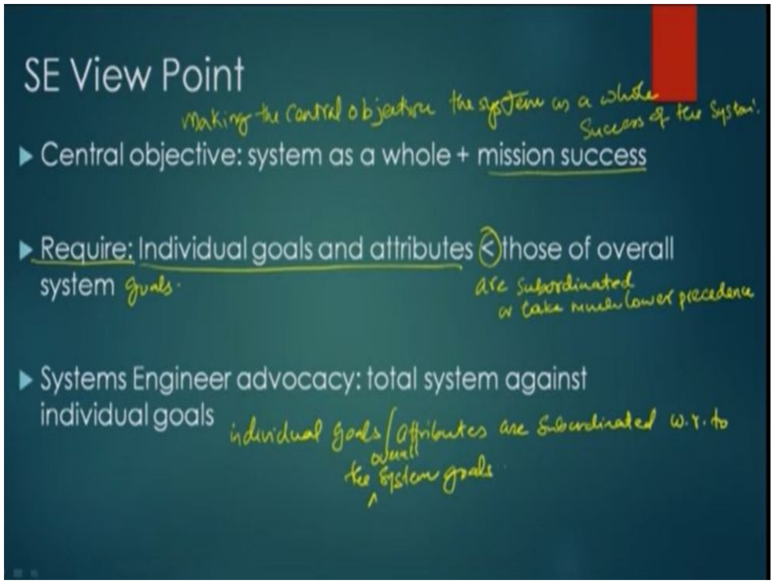

So today first let us talk about the systems engineering view point. So the central objective is of the systems engineering view point is to treat the system as a whole. And focus on the success of the mission. So it is actually making, if you write about this it is making the central objective the system. So the system is the central objective and you treat the system as a whole. You treat the system as a whole let us put it this way. You treat the system as a whole.

And you are only focusing on the success of the mission success is equal to the success of the system. You are focusing on the system as a whole and as well as you are focusing on the success of the mission. The system is supposed to perform. And you also require, this is the requirement is that individual goals and attributes we have a less than sign okay. They always take a lower priority compare to the overall system goals.

So in a better way to say is that individual goals and attributes these kind of things are subordinated. We can think about it this way are subordinated or take lower precedence or take much lower precedence. When compared with the overall system goals overall goals of the systems or system goals. So what we are saying is that the systems engineer should always have an overall view point.

Where he or she should be able to look into the overall goals of the systems and then subordinate any individual goals or attributes to a much lower precedence. And the advocacy of the systems engineer or system engineer always advocates for the total system goals against that of the individual goals. So as I said earlier individual goals/attributes are subordinated with respect to the system goals. These are the overall system goals.

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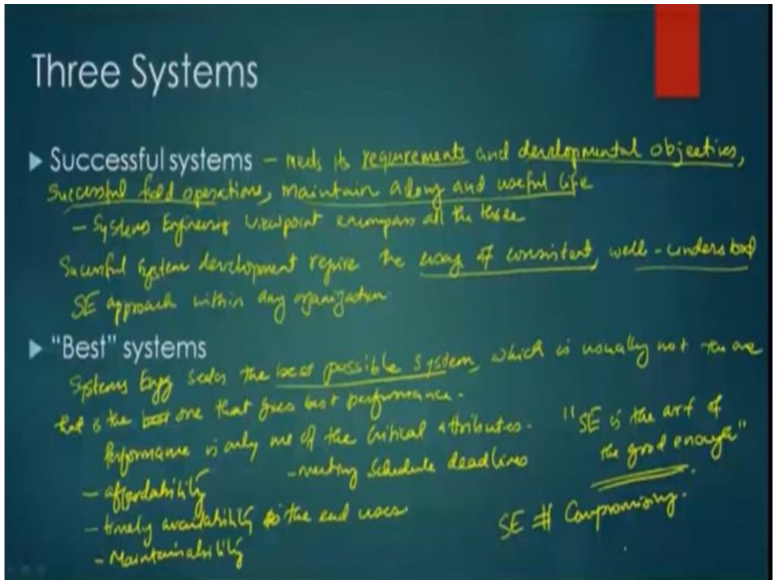

So there are three types of systems that we can talk about in systems engineering and the one that most of the people commonly talk about is successful system okay. And successful system I would like to define it this way. It is a system that meets it is requirements and developmental objectives and it also accomplishes successful field operations and in the same time maintain what? Maintain a long and a useful life.

So, successful system is a one that meets its requirements whatever the requirements of the system. And also the objectives why the system was developed the developmental objectives. Both of them the requirements and the developmental objectives are met successfully and it also conduct is able to do successful field operations when you feel the system it achieve all these objectives successfully and it maintain a long and useful life so the system has longevity.

So the system in a way systems engineering view point encompass all the three. The three means what? Meeting the requirements and objectives, successful field operations is two and maintains a long and a useful life that is the three right. So how do you develop a successful system? To develop a successful system or a successful system development requires the usage of consistent well understood systems engineering approach within any organization.

So a successful system will meet its requirements and developmental objectives. It will conduct successful field operation and it will have a long and a useful life. And all the three are encompass and to do this to develop a successful system you require the usage of a consistent well understood systems engineering approach within any organization. Then we talk about another term which is quiet important which is called as the best systems.

So the best system is a confusing term but we need to understand this many a times in normal usages in any organizations of term best systems do comes into picture. Before doing this let us see what is systems engineering seeks? The systems engineering seeks the best possible system this is important phrase. We are not seeking the best system, we are seeking the best possible system which is usual not the one that is the best performing system or that is the one that gives best performance.

So we should not ever confuse best performance with that of the best system because the performance is only one. We can say that performance is only one of the critical attributes. There are many other critical attributes. Some of the other critical attributes are affordability. It should be timely availability to the end-user. We talk about maintainability; we talk about meeting schedule deadlines so alright.

So these things are also critical attributes. So, performance mean is just one attributes. So sometimes what happens is that there is a usually saying that people sometimes says like this. Systems engineering is the art of the good enough. People do make this statement but should not really get confused with this statement because this is not just you are making compromising so systems engineering is not equal to compromising but it is about deciding the best possible system.

Not just the best performing system but the best possible system. So you cannot compromise the endurance of the system if you are making a UAV. You cannot compromise endurance of the system for speed or you cannot compromise the range of the system for endurance for something like that. You would like to have a balance or you try to create a system which will fulfill almost all the critical attributes that are part of the system and as I said earlier some of the critical attributes are listed right here.

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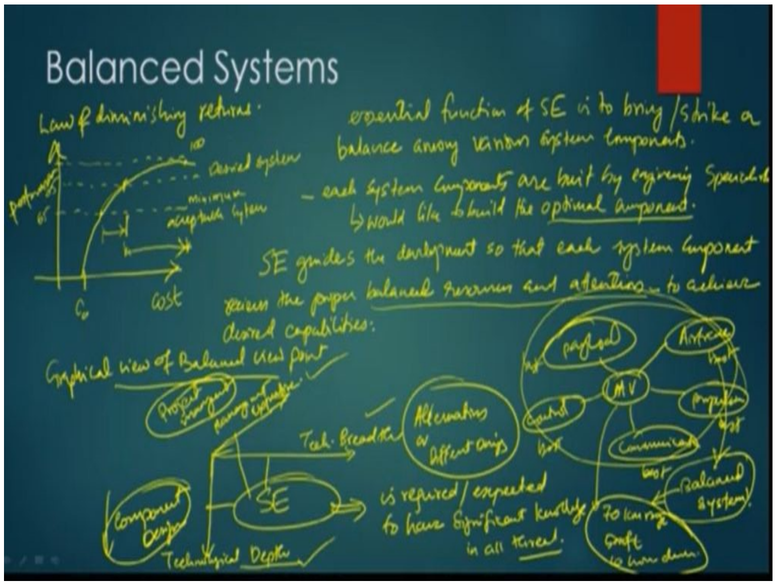

We already use this term; it is called a balanced system. I suggested earlier but there is also before we get in to this balanced system we need to understand one concept which is also called as the law of diminishing returns. I would recommend you guys to read this but the law kind of if it is represented in a pictorial graph it kind of looks sometimes like this. You have the x-axis you have cost; the y-axis you have performance.

And then you have some place were the cost begins there is Co as the initial cost and let us say this is a performance is 100% is the performance here. This is 100 or the best possible performance and the system would kind of do something like this. And somewhere here is you know think about is the system there will be a minimum acceptable system and somewhere you will have something called as a desired system.

Think about this, this could be let us say for example it could be 65% or this could be 85% the cost necessary to move from a desired system all the way to the best possible system is quite high to compare to moving from a what you call as an acceptable system to a you can see this is a movement from an acceptable to a desired system whereas this is the from desired to the what you call as the best performance system.

So this law of diminishing returns means the task you keep on putting in the money taken to or the resources necessary to make the best possible system and the return the performance that you derive from the system. It is quite significantly less for the amount of money that you put it in. So the idea here is that the balanced system it is the essential system function of the systems engineering of SE is to bring a balance or strike a balance among various system components.

When we say we have to strike balance what does it mean? So the idea is that each system components are built by engineering specialist or experts. The components are built by engineering specialist. So when they specialize is what do they want to do? Each specialist would like to build the optimal component. The person who would like to keep on improving it and making it that’s the best possible component in the world but what do SE need to do?

The systems engineer, the job is to guide the development. SE guides the development so that each system component receives the proper balanced resources and attention to achieve desired capabilities. So the systems engineer is the one where the engineering specialist would like to build the optimal component. The systems engineer would like to build the balanced component or he would like to build a component in such a way that where resources and attention is balanced.

The component will achieve what the desired capabilities are but without compromising on some other stuff. An example as I said earlier is that we talked about UAV as an example. UAV as a system where we said one component was airframe and another component was propulsions, one would be communication, another was payload and one was control. So among these five the aerospace engineer would like to build the best most efficient airframe.

And he would like to put as much as focus on to this. The mechanical engineer would like to build the most fuel efficient, most silent, longest, endurance, best operating propulsion system in the world. The communication guy would like to build a communication system that would probably communicate all the way through the Pluto or whatever it is. So the idea is everybody would like to build the best so they want to build the best communication.

They want to build the best propulsion. They want to build best airframe, they wanted to build the best payload, they want to do the best control systems and the systems engineer job is to actually say okay I understand what's your drive but what I want is a balanced system. So at some point of time the system engineer tells the aerospace engineer okay this airframe design is good enough. It is the best possible design for achieving the goals.

Because somewhere in this somebody has said I want a UAV that can fly up to 70 km range may be 500 feet latitude then turnover endurance something like this. So the system engineer tries to develop a system that meets these needs or the requirements that are established earlier. Whereas the individual engineering specialist would like to build the best possible system and another way to look at this balanced view point is we can look at it in a graphical view of balanced view point.

I would like to use a graph to represent this. We think about it as a three dimensional graph if you have three axes like this. See these are three different axes okay. This axis that is going downwards is the known thing technological depth. Here we are talking about technological breadth. And here we are talking about let us say management expertise. So the specialist if the person is more in to a technological depth if the person is a specialist in technology.

Then the person would focus more on a component design. So you can think about it as a person in a technological depth alone would focus more on a component design. A person who is on a technological breadth might be looking at developing what you call as a alternatives or different designs. This would be something that somebody might be looking course or a wide broad idea of technology.

The person who is more into a management expertise or something might be talking about a project management or something like this that might be the focus of that person. But when you a systems engineer who is supposed to have a balance among all the three okay. So this is where the systems engineer comes into picture. An effort from all the three different axes he balances all the three and so for that purpose a SE is required or expected to have significant knowledge in all three. Which are the three things? Three things are technological breadth, technological depth and management expertise.

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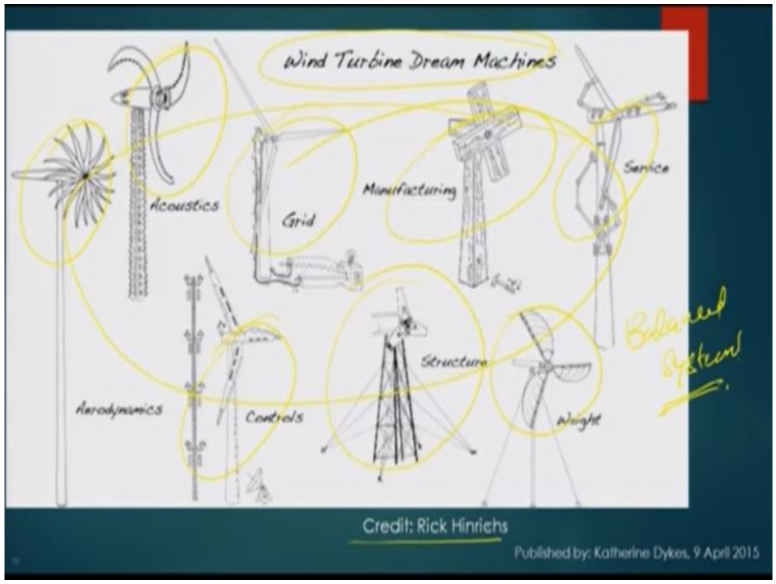

Here is an example. The credit of this diagram goes to Rick Hendricks and it was published by Katherine Dykes in an article. Let us take an example as wind turbine dream machines by different experts. So here the wind turbine is being visualized by think about the aerodynamics guys he literally focuses on making this the most efficient system which would actually be able to work in this slightest wind condition possible.

We will talk to the guy who is on the acoustics who would be more interested in designing it in such a way that it produces the minimal sound. The person who is in the control system or who is more into the control system, this is the way he may run machine in the wind mill. And the person who is on the grid, he is like I don't care how it looks like but I want the maximal electricity out of it. The person who is doing the manufacturing how cheapest I can make.

So this is the manufacturing view of it. Service person is like, can I make it in such a way that I don't need to do anything to service it or the minimum serviceability. The person who want to make this as part of the weight or the structure guy of the weight, person who is thinking about the reducing the weight or optimizing the weight he might create a system like this we have to say okay fine.

Let the blades be made of paper and the structure guys like okay I want to ensure it in such way that it will not fall even if the entire earth rifles apart in to two or three pieces. So what I am trying to say is that every expert has its own view point. The aim of the system engineering is to get input from the aerodynamic person, the acoustics person, the person who is managing the grid, the manufacturer, the service guy, controls guy structure guy and weight guy and all of these he wishes to integrate and create what we call as a balanced system.

The inputs are vital but what to take and what not to take is the aspect of the systems engineer. I think this diagram even again credit goes to Rick Hendricks. He is the one who actually came up with this good diagram which gets a point across how the systems engineer strikes a balance among a bunch of experts.

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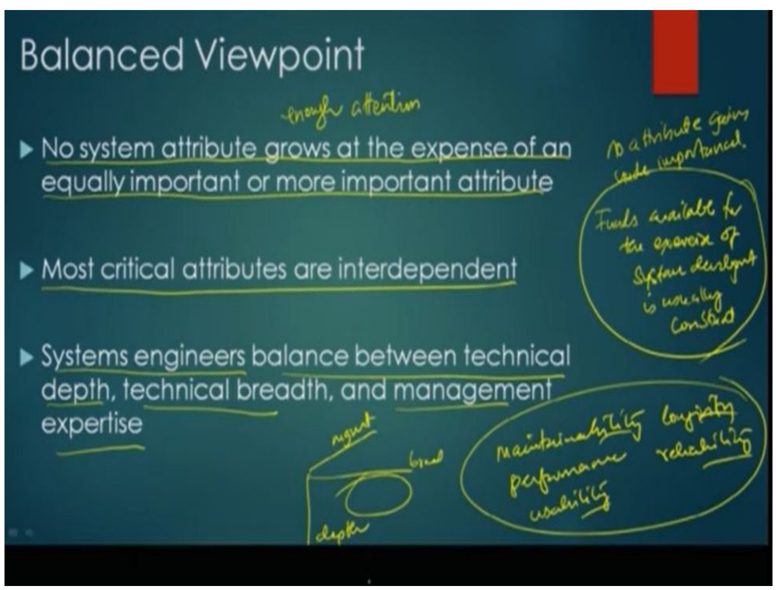

So we now talk about the balanced view point and the balance view point is very simple. It basically says this no system attributes grows at the expense of an equally important or more important attribute so a systems engineer should ensure that no system attribute gains undue importance. We here is that no attribute gains undue importance. So the systems engineer ensures that if because what happens is if you put undue attention to one of the attributes.

Then it will impact the some other equally important attribute because the total money available is constant. The consumption here is funds available for the exercise of system development is usually constant so this is an important aspect. See you do not have infinity sources or funds. The idea is that you have to ensure that sufficient or enough attention is given to all attributes and nobody gets an undue attention or no attribute get an undue attention.

And other aspect is this is kind of a truth most of the critical attributes are interdependent. So I said earlier some of the critical attributes being maintainability obviously performance is another one. Then usability, longevity, reliability and many of those kinds of things the many "lities" is part of this process. So all these ones are interdependent, so if twig one somebody else will get twigged in a way that you did not except or you need not want.

So as I said earlier all these attributes being interdependent so that where no system attributes grows at the expense of another equally important attributes. So hence the systems engineer balance between the technical depth, technical breath and the management expertise. You remember the previous diagram that we drew like this. The technical breadth, the depth and the management and the system engineer's job is to strike the balance among all this.

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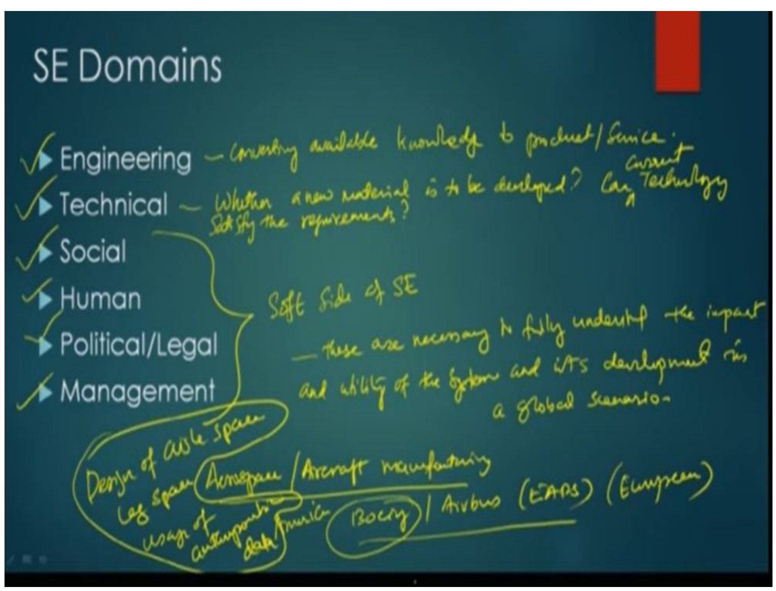

So now we will from here we will jump in to the systems engineering domains okay. So the domains are like one is engineering obviously so engineering you can think about it is converting available knowledge to product/service. For the time being let us assumed engineering to be something like this, so here is where the things actually get made. Then there is also the technical domain sometimes for example is we consider sometimes whether a new material is to be developed.

Can current technology satisfy the requirements? So can we build a system with the current technology that will fulfill it is beings or demands. So that question comes from the technical side that question gets answered sometimes new technology that need to be developed that all aspects comes as part of it. The social aspect to a large extend is the social, human, political, legal, management these kind of things that many people sometimes call us as the soft side of systems engineering.

Are they really required? And yes this is required because these are necessary to fully understand the impact and utility of the system and its development in a global scenario. A classic example of this is that if you think about the aerospace industry or the aircraft industry aircraft manufacturing. If you look at the histories of the companies like Boeing or Airbus or EADS, we can see that initially they focused as more towards the developing aircrafts which are important to their locality.

Like the Boeing was focused more on the America continent and the Airbus was focused more on European because that is where the air travel originated and flourished. But pretty soon as the global market opened up other continents need to be connected and people started moving from continents to continents and other stuff. When the market became global when market grew outside these companies actually started looking into the different aspects of it.

Like for example the design of aisle space or the leg space or usage of anthropometric data. All these things were done as part of the social human and other aspects of the design the soft side of the design being added in to the system so this provided the airline agencies or airlines to customize their aircraft to the needs to the population that they survive or so.

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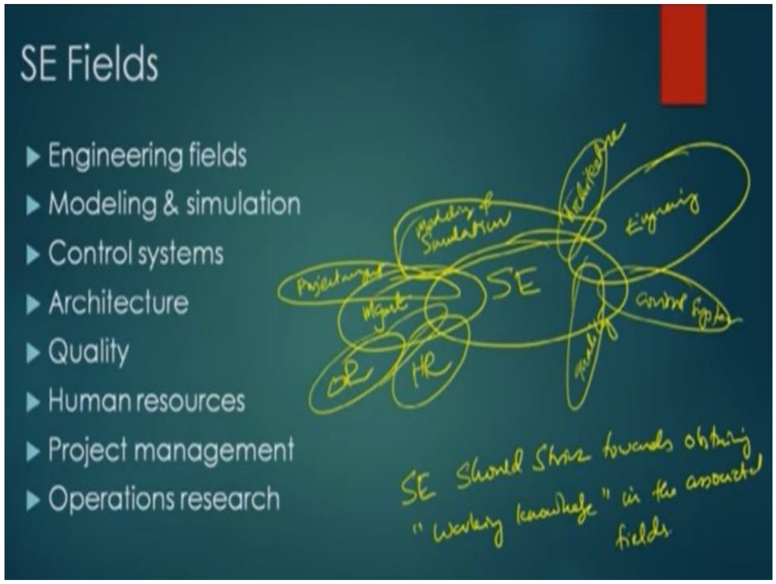

Now we also talk about the systems engineering fields so there is the engineering field. Then there is a modeling simulation, control system, architecture and quality. These are the major engineering fields. So if I represent them on a diagram let us think about this first bubble as systems engineering bubble and let us think about this bubble as the management bubble. And let us think about this bubble as the engineering bubble.

Then some of the tools that we talk about that it is like for example architecture is like something like this. Architecture will be systems engineering and an engineering bubble contribution. There you are doing product architecture or process architecture or something like that. Similarly, another one would be control systems this will be quite a lot into an engineering domain as such. You could also even thing about something like a quality as a part of this.

How do you produce a quality product and stuff like that? But somewhere in the whole ambit of the things you might have a bubble something like this which we can call it as a modeling and simulation. So some aspects of management like simulation or modeling of the production systems or something like that or simulation of manufacturing system. Similarly, in engineering there is something called as a colorful or the CFD which we call as colorful fluid dynamics but any way all thus had and done.

The CFD is another example of a simulation that has been done as part of engineering. In management we again have thing like management assistance engineering, we have HR or human resources. We have some stuff called OR operation research which is again part of systems engineering and management. I draw the bubble long. Then more in to a management of systems engineering is the project management.

So there are different fields in engineering or the management which shares common boundary between the systems engineering and one of the either management or engineering. So what I am trying to say is that these fields it might be important for people to be experts in certain fields but systems engineer should strive towards obtaining “working knowledge”. I am using the term working knowledge in a quotation because in the associated fields.

This is important in this case. So while there are wide varieties and there are experts available the systems engineer should know when the experts say something what he or she means? He may not know the nitty-gritty details but he should have sufficient capability to understand what the whole discussion is all about.

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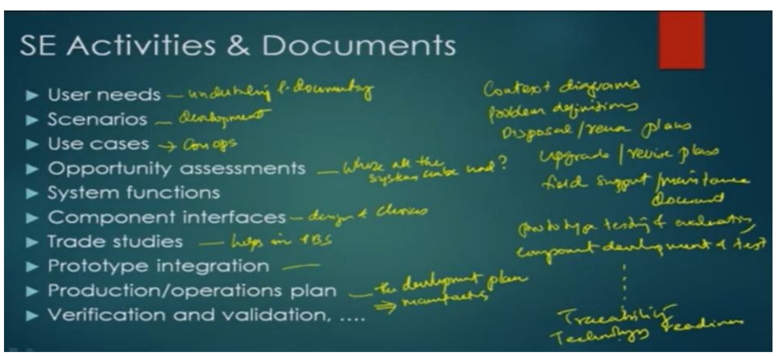

Then we talk about certain the activities and documents of the systems engineering so the user needs understanding and documenting is one of the activity. Developing the scenarios, the scenarios where the system will use so the development of them and making them into document developing used case okay. So this is where the con or concept of operations will actually get linked with it.

So say development of the used cases, you look at opportunity assessment so like where all the systems can be used. What are the other opportunities that are available as part of the system development? The functions – the documentation of the systems functions, the design and choices of component interfaces is one part of it. We already saw how we do documentation for trade studies as part of this because this helps in the PBS the product breakdown structure.

You already talked about this. How do we integrate prototypes? And how do we develop a production and operations plan when the development plan is translated to manufacturing or production plan something like this. Verification validation and then there are other aspects also called context diagrams. Then there are other aspects called the problem definitions. Then we have disposal/reuse plans. How do we develop those kinds of things?

How do we dispose the product? There we do have one upgrade/revise plans this is another aspect of it. Then we have a field support and maintenance document okay. We also have a prototype testing and valuation. We also have the component development and test. Like this we have quite a lot of documents that are available. Other stuff like the feasibility that we already talked about that is stuff like the technology readiness etc.

So there is numerable number of activities and documents that are done as part of systems engineer and this is necessary because this is where the entire document of how this complex system has been developed. And it is required because it will also serve as the knowledge base for the future activities to come. So with this what we will try to do is we will try to actually we studied the systems life cycle and why life cycle of a product is important.

So we will try to capture the entire system lifecycle and its critical aspects using block diagrams so that we can review what we have done so far before we jump into a specific aspects and tools of systems engineering.

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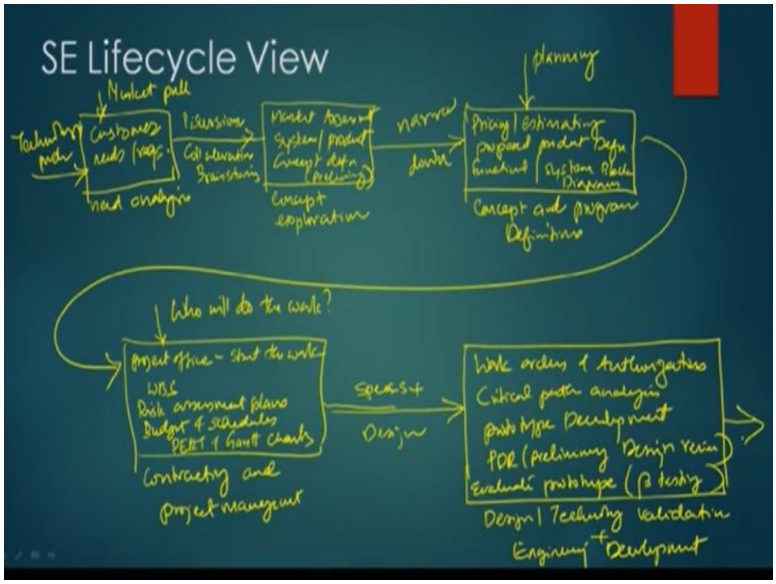

So the initial part as we said earlier if we draw it as a block diagrams. The first thing that we are going to is the need analysis. We talked about this what it is? Further details will be available to us in the future slides but the one of the thing actually comes into this is the market pulled information. Then there is something else that is called as the technology push like. For example, is why would the countries keep on building a third generation fighter, fourth generation fighter, fifth generation fighter keep on upgrading the fighter.

Because that's where the technology push comes in to picture. Newer technology means newer capabilities additional capabilities better rate of success and stuff like that and similarly their might be a need for you might be in the productive business building selling aircrafts. Then there might be a market pull. The people who are buying the aircraft might be looking for a better product so you need to keep on upgrading the product.

So the one major aspect of all of this is the customer requirements or customer needs/requirements. So the need analysis from here it is developed and then it moves in to the next stuff which we kind of make another square which we called as concept exploration. So from here from the need analysis to concept exploration we will have discussion we will have collaborations, we will have brainstorming etc., okay.

And in this case the major thing that will happen is the market assessment happened. The market assessment then the system and product concept definitions we also have this, this will be preliminary okay. So we are exploring the concepts what are the possible options, what are the possible concepts that the system is capable of. What are the possible configurations? or concepts that can be explore to release the system.

And from there we basically get in to the definition so the third will be concept and program definitions. So you have gone through lot of exploration, from here now we are defining things so this is where the idea of planning comes in to picture where you have pricing or estimating here you are deciding how much it is going to cost we do the proposed product definition. We also do the functional or the system block diagrams.

So, all of these things are done as part of the concept and the program definition. So, the planning of how to execute the system so the from the exploration you have narrowed down you are bringing it down to a concept that you think it is feasible and the detail aspects of it is being created from here we get in to the next one next box as we call it. Let us call it as the contracting and project management box.

In this what happens is the project office or the start the work gets established. Then the WBS or work-based schedule or the how do the work gets divided that gets done. Risk assessment plans get built at this point what’s the risk that we process, the budget and schedules. So here we had making the how much of the pricing the estimating of this. Here the detailed budgets and schedules gets build. Then you also get up making the PERT and the Gantt Charts.

Again I switch the development will work for work. And then from there we move to the next bubble or the next box where we actually do is the information that flows is specs or the specification plus the design. The tentative design flows from the contracting and the project management. So at this point you are identified somewhere identified who will do the work? This question asks me to identify to some level here.

So in the second stuff once this is done then we do the next phase which is called as design/technology validation plus engineering development. So in this the major activities that we do is the work orders and authorizations then we have the critical path analysis which are the critical activities that needs more focus then you do a prototype development. You also have the PDR which is called as the preliminary design review.

Then we also have something called as a evaluate prototype. It is also called as the beta testing okay so all these aspects are part of the design and technology validation plus the engineering development. From here we move to the next step. So you can see that we started with the need analysis with the components of it then concept exploration you are exploring widely what are the options available from there you narrowed due to concept and program definition.

From there you do the contracting and project management. Then you moved to design and technology validation plus engineering development.

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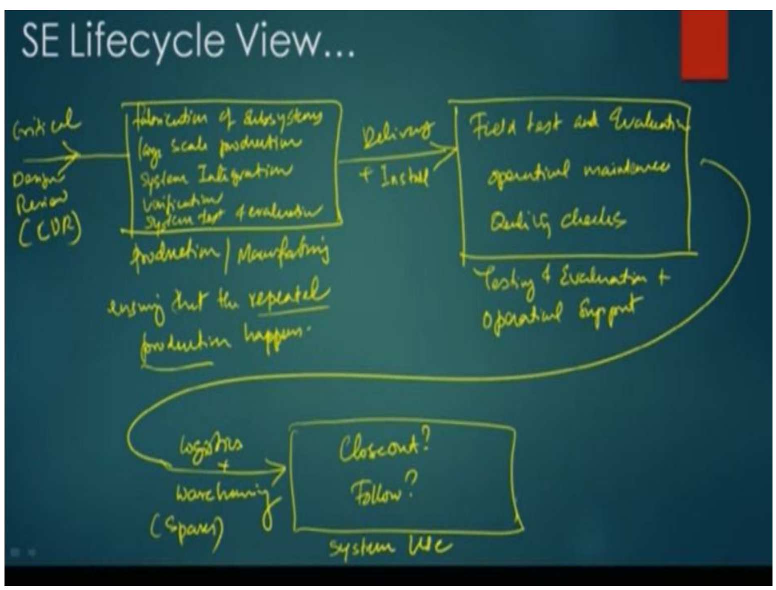

From there we get in to the next part the next bubble which there is something called critical design review or CDR. This is done and it goes in to another big box and let us call this big box as production or manufacturing. We can also call it as development of the system. Here the aim is that you do fabrication of sub-systems, so the prototype has been designed and agreed and the critical design review said okay let us go ahead and make it.

So the sub-systems are been fabricated the large scale production. So the same uniform product gets produced. System integration the sub-systems that have produced get integrated then you do verification to ensure that the integration is correct. Then you do system test and evaluation. So here you are doing the large scale production. So here to a large extent you are ensuring that the repeated production happens.

Repeated production of what? The desired system happens. From there we move to the next box which does the delivery plus install. So this box what we call this as the testing and evaluation plus operational support. Here you do the testing this is mostly like into the field test not the product testing. So you are taking the product in to the operational area and then doing the field testing and evaluating then you also do operational maintenance also part of this.

And we also do what we call as the quality checks and supports as a part of that as well. From here we get in to the next bubble which we call as the last bubble where now the system is in the place where it is operating and all so this is the system use bubble or the rectangle where what we decide stuff like close out okay or should we do a follow up of this. Continue to develop further. So here the major important things are the logistics and warehousing.

So here the system is operational you are supporting it so here you have your space and other aspects as part of it okay. So after some point of time you decided that okay fine the system is not doing as well as it is expected. For a better system available so shall we close out it, shall we shut down the development or the system is doing extremely well can we continue to develop a further different version of it all these aspects get done out of it.

So from the previous slide started with the technology push and the market pull which started the need analysis from all the way to the system use where we decide the close out or the follow up is a graphically can kind of call it as a flow chart view of the system life cycle and there are tools this whole lifecycle is controlled over side by the systems engineering and there are different tools and techniques available at each stages to make the appropriate decision.

We will now start seeing these tools and so the next lecture will be on the system building blocks and after that we will get in to different tools and the aspects of the systems engineering. Thank you very much for the patient listening.