Systems Engineering
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Lecture - 01
Systems engineering – What is, origin, and examples

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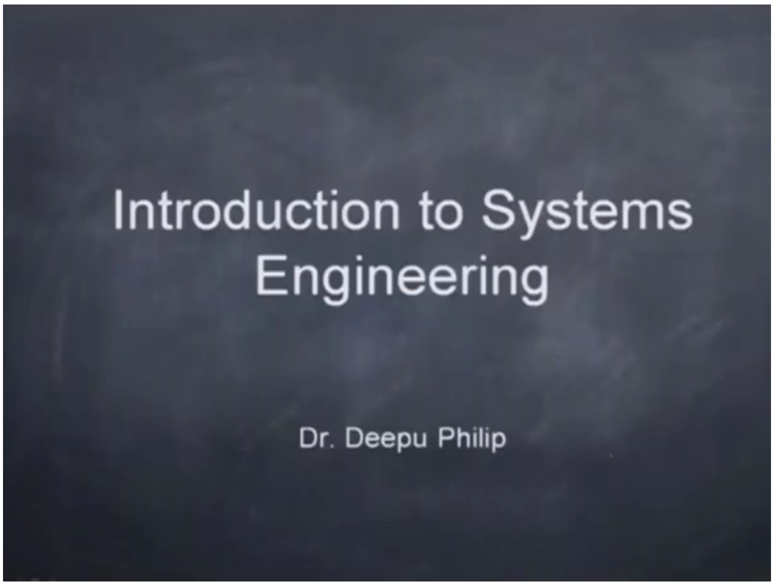

Good morning everyone. Today we are going to start with the course on systems engineering and today is the first lecture. It is on the introduction to systems engineering and I am Dr. Deepu Philip and I am from IIT, Kanpur and I am a faculty in the Industrial & Management Engineering department and as well as the design program and I am a systems engineer by trade.

Before, we get into the details of Systems Engineering, let us start talk about how the dynamics of this course will work.

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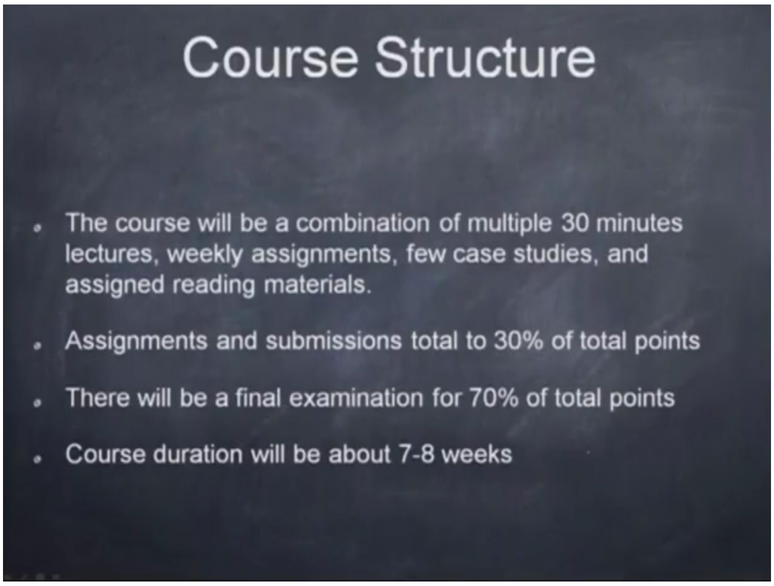

This point this course will be combination of multiple 30 minute lectures which will be delivered to you, which you are expected to listen and then followed by weekly assignments which the student will use materials available and provide as part of the course to read and complete the assignments. There will be few real time case studies given which student is supposed to read and understand and then answer the questions that follows the case studies.

And also there are some will be weekly assigned grading which also is responsibility of the student. So it is a mutual course in which both the participation from the students are also equally important. The assignments and the submission worth a total of 30 points or 30% of the total points and the final examination will be worth 70% of the total points and the duration of the course is about 7 to 8 weeks.

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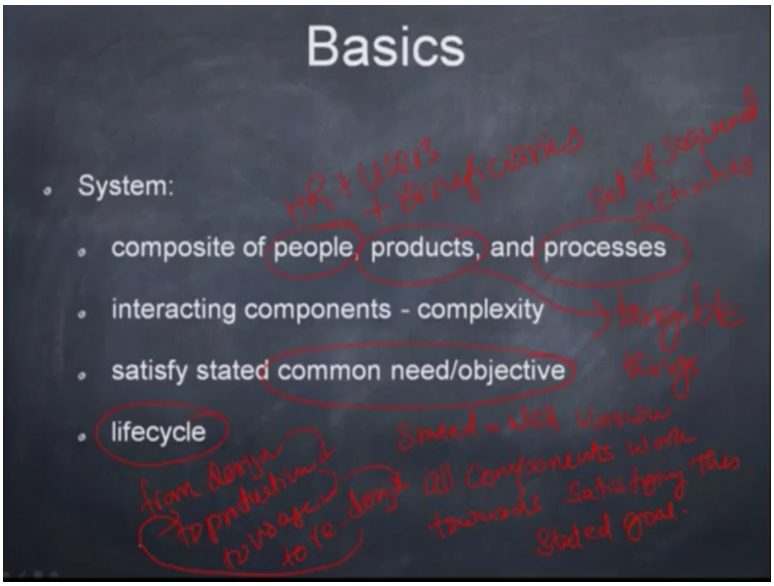

The basics of the system, let us talk about the basics of the system as such or what are the simplest things about a system. There are many definitions available to the system but for the purpose of the course we will look system as a composite of people products and processes. So when you talk about people this part, the first part is all about manpower which mostly involves the human resources which sometimes people call as HR plus the uses of the system and as well as the people who are basically the beneficiaries of it.

So all these things put together gives the component of the people. The products are really tangible things. Let us put it as tangible things for the time being. We will elaborate this later and processes is typically the set of sequenced activities. These sequenced activities will result in creating product or a subassembly of the product.

So a system is a composite. Composite means it is a conglomeration or a mix of all these things and another aspect of the systems is that these components also interact with each other. Interaction means the people will interact with the machines, the subassemblies, the product, the components, the processes, so everybody working together in an unition to really create what we call as a final product.

In this case we are not talking too much about the services components, we are mostly focused on product side itself. But these interactions actually create complexity, because when there is a man and a machine interaction there is an interface and that interface usually creates additional complexities. There is a stated common need on an objective. That means the system as a whole has one common objective which is stated.

Stated means it is known well known to everyone. So this objective is stated and everybody, all components work towards satisfying this stated goal or objective or need. Then other aspect that actually comes out of this is a term called lifecycle. People use lifecycle in the sense that it is the lifecycle of a product or a system or a human being or something like that. Here what we talk about lifecycle is that the end to end, from design to production to usage to redesign.

So it is a cycle where you start from the design, then you move to the production, from production you move to the usage, from usage to the redesign and so the cycle continues. So the lifecycle of a product is actually is - a mechanism in which the product goes through multiple iterations and improvements. So all these are aspects, the terms that we will come through in the discussion of this course.

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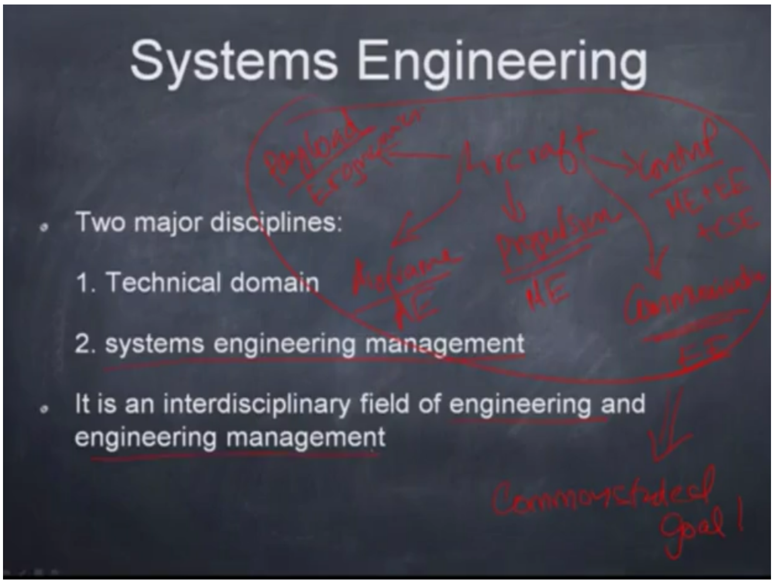

In systems engineering there are two major disciplines. We need to talk about. The first one is actually called as technical domain. The technically domain particularly deals with the technical knowhow of the product development. So let us say that you are working on development of aircraft. So an aircraft typically has 5, we can think about it in 5 parts. One is an airframe, then there is propulsion, then there is a control, which is an autopilot and other kind of things.

Then usually there is a payload or whatever you call as the human beings that we are being carried and as well as the last part is the communication. So the technical knowhow here this might require a mechanical engineering, this might require an aerospace engineering. This might be knowledge in mechanical plus electrical engineering. This might be an electrical engineering specialty. This might also require computer science engineering.

This would require what you call as the ergonomics people, human factors and stuff like that. So this is the technical aspect of systems engineering. Multiple drivers technically know, how is necessary to realize a product. But another aspect of it is, all of these things that we just wrote here need to be managed together to realize the common stated goal. This part is the aspect of the systems engineering and management.

How do the diverse aspects, technical aspects of the system? Gets managed towards realizing the stated goal? So strictly speaking systems engineering is a very strong interdisciplinary field which is a field of engineering and engineering management.

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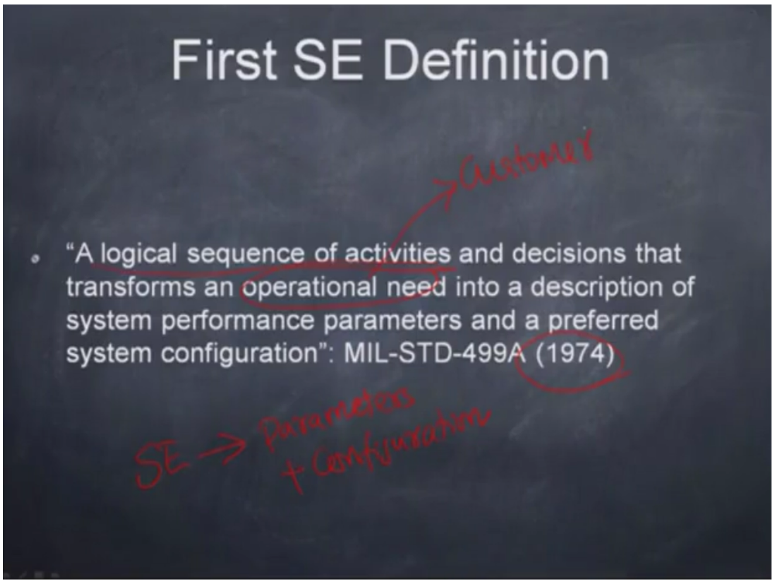

So initially let us talk about the definitions how systems engineering evolved as a discipline. So you can see that it started in 1974. This is the military definition MIL standard 499A. It is no longer a, it is depreciated. People say that it is an outdated definition but still this is where systems engineering began. So the origins can be traced with the defense or military background and the initial definition read something like this.

A logical sequence of activities and decisions that transforms an operational need into a description of system performance parameters and a preferred system configuration. So initially systems engineering SE was targeted more towards developing parameters of a system, the performance parameters of the system plus the configuration of the system. So this is where the systems engineering began.

What are the specific parameters of the system? or what are the logical sequence of activities and decisions that can transform this operational need, this is by the customer. Whatever is the operational need of the customer how can it be realized with a set of system performance parameters and a preferred configuration? So initially systems engineering was limited to this 1974 and this is where the humble origins of it happened.

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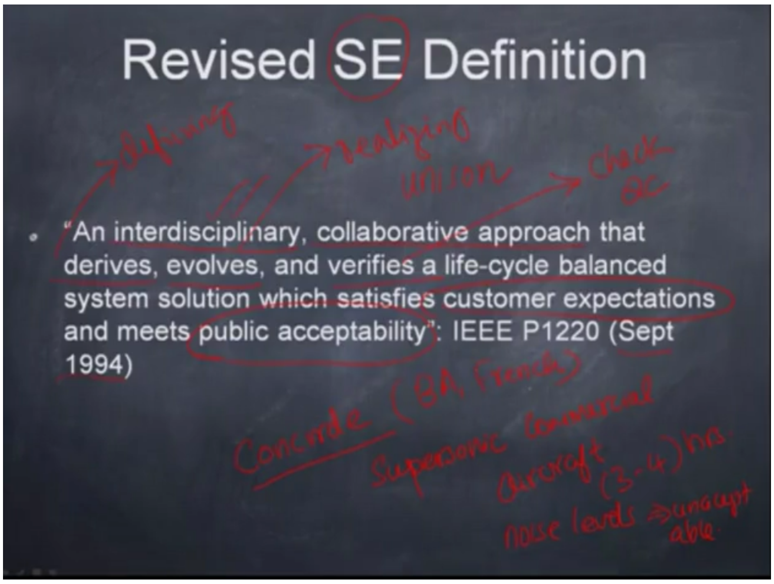

From there next move to the next definition which is something called as a revised definition. So the SE, by the way for this acronym stands for systems engineering and the revised definition states something like this, an interdisciplinary, this is the first word, collaborative approach that derives, evolves and verifies a lifecycle balanced system solution which satisfies customer expectation and meet public acceptability.

It was in the IEEE P1220 September 1994 definition as you can see, here we can see that the definition has evolved much more significantly. The concept of interdisciplinarity where multiple technical fields of engineering to be collaborated together. So the collaboration concept, collaborative approach they are working in unison, this concept started coming in, that derives, evolves and verifies.

So derives this is the point in which you are basically defining the parameters and evolves is how are you realizing the parameters and verifies, this is where the, you can think about it as a check, quality control, something like that of the lifecycle based system, we are not talking about a product, we are talking about a system, solution that satisfy the customer expectation.

So you take the customer expectations and from there you derive the parameters and from there you evolve the system design and from there you verify that the evolution, evolved systems design meets the defining parameters of the customer expectation and this concept of public acceptability was also included at that time. Public acceptability to a large extent is the classic example of this is the state of aircraft called Concord which was designed as a supersonic commercial aircraft.

I would recommend you guys to read about it. This aircraft, it could travel from London to New York in like 3-4 hours, between 3 and 4 hours. So it has reduced travel time into half when it is compared to the normal travel time. But Concord was stopped. One of the main reason was because of the noise levels at landing and takeoff which was unacceptable. So this was the reason this product was not being supported by the general public.

And the public acceptability was not there. Hence, Concord services had to be shutdown. So read about this Concord aircraft of both British Airways and French Systems as well. So the public acceptability was an important aspect in the definition when the systems engineering definition was revised.

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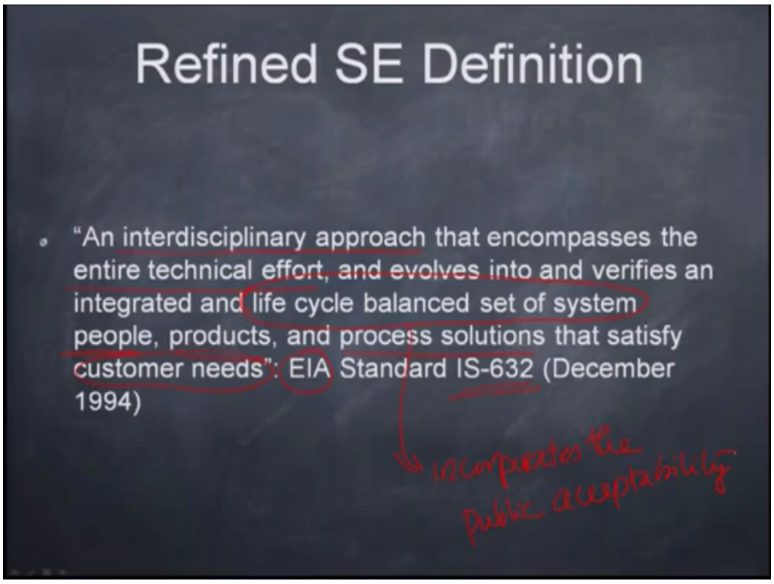

Then the definition got refined further. It is in the December 1994, EIA stands for electronic association. So what they ended up doing is that the IS-632 standard, the systems engineering definition was further refined to be again and interdisciplinary approach. So the interdisciplinary concept remained that encompasses the entire technical effort. It just did not talk about starting from the deriving the specification from the customer needs.

It talked about the entire technical effort related to the system design. So this entire technical effort and evolution or evolves into and verifies an integrated and lifecycle balanced set of systems people. So here the concepts, the major aspects of the system, the people, the products and process solutions that satisfy the customer needs. So these 3 aspects of the system, the people, the products and the processes was spelled out in this definition and the customer needs again you can see that it stays.

One of the question that people actually ask here is, what happened to the public acceptability? Did it got dropped? Well, public acceptability is still there. The aspect is there. The lifecycles balanced set of system, this incorporates the public acceptability. So these definitions when you see that slowly ward over time and as the systems engineering spread it wings and the evolution of this discipline into an umbrella system that actually guides the development of a complex system.

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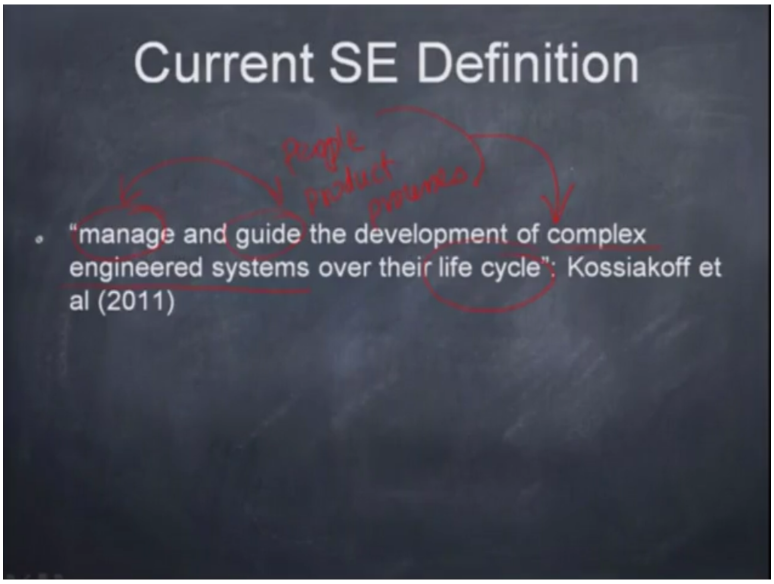

Now with this, we move to the what we call as a current systems engineering definition to a large extent the Kossiakoff et al., in 2001 has provided this definition which is a much more simpler definition. What it is, it is the manage or the management, manage and guide the development of complex engineered systems over their lifecycle. So you can see that definition is now to complex engineering systems.

To a large extent we are not involving the life systems or ecological systems in this case. We are talking about engineering systems or manmade systems and the lifecycle of the systems is still an important aspect, s throughout the entire lifecycle. And manage and guide is suppose to half all the aspects that we talked about, the people, the product, and the processes. That relates to the development.

So all of these results in the development of the complex system. So it is a much simpler, shorter definition but lot of things are hidden together into this. So the essence remains the same, it does not change too much, but the definitions as you can see it increased the scope of the systems engineering.

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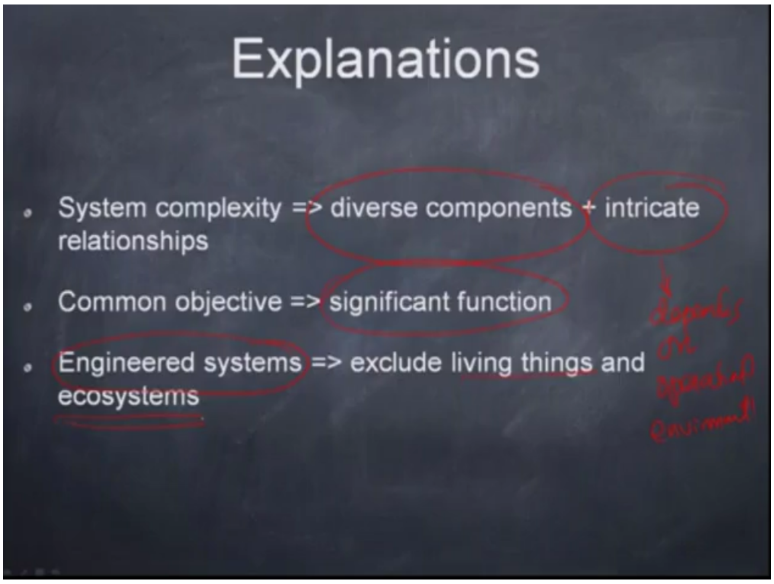

So some of the explanations to just recap on what we discussed so far. So system complexity, one of the term we talked about complex systems, design of complex systems, so what is a complex system in a simple way. So if you talk about a washing machine at home that is not a complex system because it is household systems are refrigerator, many people do not consider it as a complex system anymore.

But if you talk about an aircraft, you talk about a communications systems, you talk about a missile system or integrated command and control systems or you talk about a transportation system, all of these kind of things, the complexity where you have multiple diverse components interactive together. So the diversity of the components to a large extent determines the complexity of the system and many of these components have intricate relationship with each other.

When you have diverse components interacting with each other, the relationship sometimes becomes intricate. Like for example in an aircraft, the control might tell the deflection of control surface to be 2 degrees or 3 degrees up, down something like that. So plus 2 degrees or minus 3 degrees. But what does that translate to the change in the behavior of the aircraft or how does the aerodynamic forces actually gets translated.

That is something that is a job of an aerospace engineer. He might have given this, okay, if you deflect it by 2 degrees, plus 2 degrees then this is what will happen to the aircraft. If you deflect the elevator minus 2 degrees then this is what is going to happen. He has already provided that information, but that intricate relationship gets translated to a computer program which actually ensures that the control surface is deflected by that exact degrees.

So that is an example of a complexity and this deflection to a large extent depends up on the speed. So if it is flying faster you might not require that much of deflection to generate the same amount of force. So as the operational environment changes this intricate relationship, so this to a large extent depends on operational environment. Also other parties, a common objectives, all these systems, all these components should have a common objective which is a significant function of the system.

So the significant function of the system on aircraft system is to fly people from place A to place B safely or transport cargo from place A to place B or deliver ammunition at a precise location as quickly as possible. The significant function is that and how it achieves the significant function, the common objective is the important aspect of the systems engineering. As we have said it is an engineered system, so we exclude all living things and ecosystems. So we are not studying about how the plants and the flora fauna or a forest as an ecological system we are not worried about that. We are more worried about manmade human systems.

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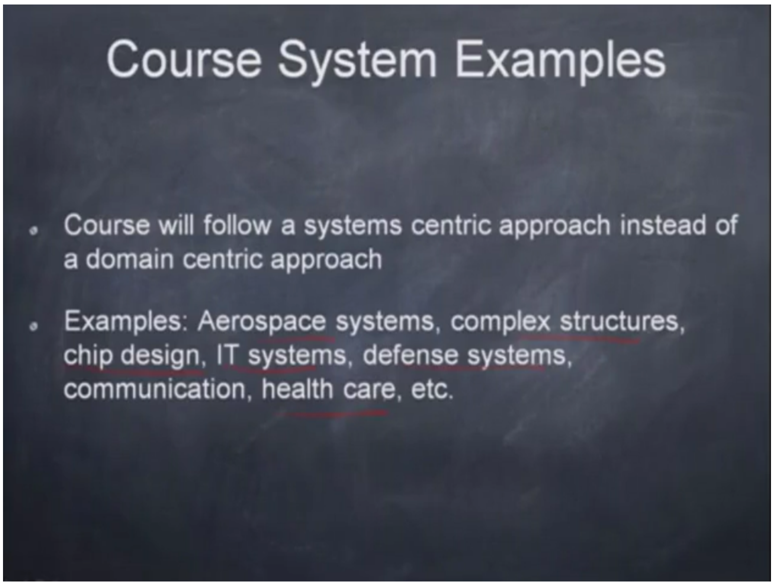

Some of the examples, see in this case, this course, we are typically going to follow on a system centric approach instead of a domain centric approach. So we are not going to look at system from an electrical engineering standpoint or a mechanical engineering standpoint or an aerospace engineering standpoint.

Instead we would actually look at ourselves as an aircraft or a transportation system or a communication system and the components of it and how different domains interacting the system to realize their successful common stated goal. Some of the examples as I mentioned before aerospace systems, complex structures, the chip design which is in fact a complex system, IT systems, IT enabled systems actually, defense system, healthcare is another complex example, complex system design examples.

So we can see that systems engineering is not just limited to one field of engineering, it is actually spread across the technical domains of different engineering disciplines.

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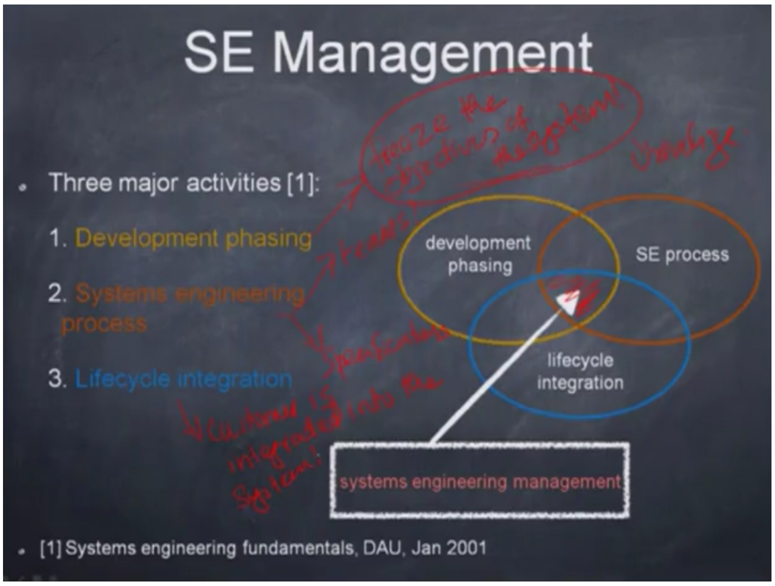

So let us talk about the systems engineering management because we said, the current definition says manage and guide the development of a complex system. So what is the management component of this? So this actually, the credit goes to the system engineering fundamentals by the defense university DAU and it is a January 2001 document.

It actually says the systems engineering management aspect has 3 major activities and the first one is called the development phasing. We will go through each one of them in the subsequent lectures, following this lecture we will discuss the details of it and we will go through the intricate details of each one of them what does this actually means. So the number one is development phasing, number two is systems engineering process and number three is lifecycle integration. So how do these three behave together?

So the first one we can think about is the development phasing followed by what we call as a systems engineering process which actually overlaps with the development phasing. On the top of this then we have the lifecycle integration that integrates with all the three and from there we get what we call as the systems engineering management. So this red bubble where everything comes together, we can think about that is a place where the systems engineering management finds its aspect together.

So the development phasing to a large extent is the first phase of systems engineering and this is where we specifically freeze the objectives of the system. What happens here is we derive what are the major objectives, what are the things that the systems need to achieve as part of this?

What are the major functionalities or not the major functionalities, the right way to say it is like, let us say for example if you talk to the people in Boeing and ask them what was your development phasing, when you developed Dreamliner 787 what was the major aspect of it. So it was turned out to be a very successful long range career which was minimal noise and vibration levels and as well as extremely fuel efficient.

So that important aspects, important stated goals and objectives actually comes out as a result of this development phasing. Once that comes in, second step comes is the systems engineering process. So once you have the objectives, then from there you need to derive something called as specifications, the systems specifications. What will be? So when you say that okay this has to be a fuel efficient aircraft, what is fuel efficiency?

How many nautical miles per gallon of aviation turbine fuel or it should be the most silent aircraft, so then what is the noise level, specify the noise level, how many decibel is acceptable. Also said that it should be, most of the aircraft component should be made of composites, what percentage? 10%, 20%, 30%, 40%, 50%. So the objectives that are loosely stated in English gets translated to quantitative measurable and verifiable facts.

That is the major aspects of systems engineering process, the second stage. There is one more thing that actually happens out of these systems engineering process, the teams that will realize different aspects of the product development or the complex system development that we talk about, also gets formed as part of this procedure.

The team in the sense, the teams like somewhat we will be for example, if we take the Dreamliner 787 case, there is a team that will be focused on developing the engine which is fuel efficient, minimal vibration but also able to give sufficient speed to the aircraft. So then they will exclusively work with some set of people, their aim is to basically realize that.

Then there will be another team who is the materials team whose job is to how to integrate different composite materials with the typically accepted body on an aircraft which is made out of an alloy called Duralumin, so they will be focusing on that. So there are different type of teams who will actually focus on different aspects of the system and the systems engineering, a system engineers job is to actually manage and actually supervise or in a sense guide that teams in realizing the stated objectives of the system.

So the aim is to realize these, okay? Once this is done, once the specifications and the teams are frozen out, then comes the lifecycle integration because one of the things is at the end of the day whatever product or whatever systems you designed, if the customer does not like it, it is not going to fly. So this is where the lifecycle integration is where the customer is integrated into the system, means the customer decides whether this is the right thing to do or this is the stuff that he or she needs to change or what are the other evolutions that are need to be part of this stuff. That all comes as part of this.

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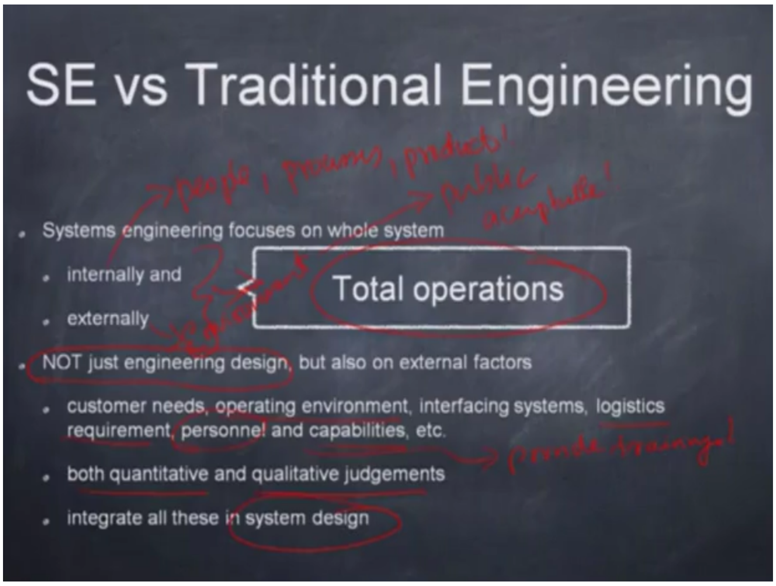

So quickly we will talk about systems engineering and the traditional engineering differs and what are similarities. The systems engineering always walk us on the whole system. It looks at the system internally which is the people processes and the product subassemblies and it also looks at it externally. So the internal aspect is the people, processes and products or subassemblies whatever you want to call it where as externally that is the environment.

We talk about the public acceptability. This concept comes out of here. So both the environment in which the system operates and the internal aspect of the system both are looked into, so that results in the total operations. These two together gives you the total operations of the system. So it is not just an engineering design, please remember this. This is one of the most important aspects.

It is not just an engineering design but it also has external factors on it. So the customer needs, the operating environment, interfacing systems, logistics requirement, what type of things are required to transport it from place A to place B. Do we have the sufficient personnel to operate the system, are there enough capabilities, or do we need to provide additional trainings or trading, all these kind of things are part of the systems design.

You have to make qualitative and quantitative judgment. Qualitative means you cannot have everything measured by a number. Like for example what should we paint the aircraft, what should be the painting scheme of this. You cannot say that this must percentage white or something like that. You might say okay it could be a mix of these because it gives you a different appearance.

You might want to say that you might want to paint it with a paint that might reduce the skin friction drags so that the noise and vibration levels are reduced. So how much you can reduce, you can probably quantify. But then the aesthetic appeal might be a qualitative judgment. So the systems engineering also involves both qualitative and quantitative judgment and all of these things are integrated into the final design of the system. Together with that, so this is the difference between a system engineering approach and the traditional engineering.

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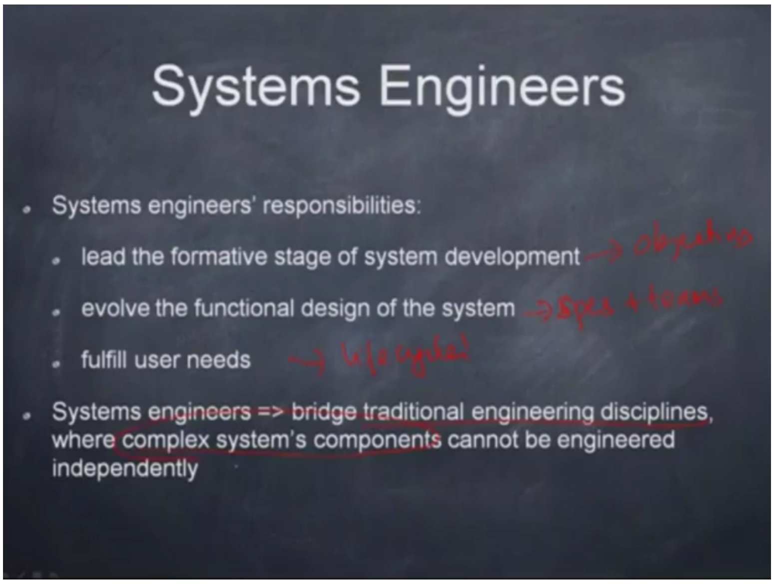

And who are systems engineers? They are major responsibilities include lead the formative stage of the system development, the first phase, where you actually evolve the functional design of the system, where you come with specifications as well as the team. So here is the objectives, here is the specs plus teams and then here is the lifecycle. So they bridge the traditional disciplines.

So systems engineers are to a large extent jack of all trade, master of none kind of a thing where their major aim is to engineer complex systems where it cannot be, they are such a complex system as so many diverse technological skills necessary so that cannot be engineered independently.

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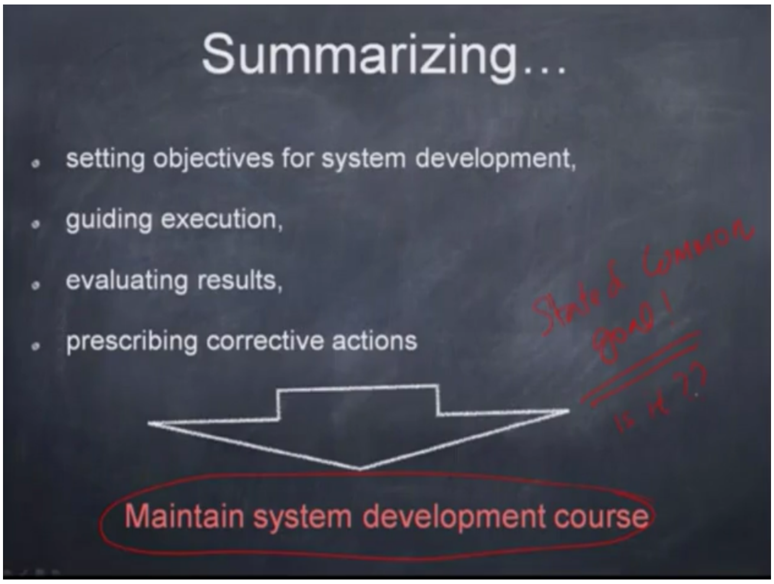

So summarizing today’s lecture what we talked about it is the system engineering is all about setting objectives for the system development and then guiding the execution. Once the execution is over, you evaluate the results, again as the customer specifications or customer needs and prescribing corrective actions.

All of these will ensure with one goal. Maintain the systems development in course, keep the systems development in track and ensure that the system development process in such a way that the stated common goal, this is the most important aspect of systems engineering, what are suppose to achieve? Is it getting achieved? This question is something that keeps the system engineers on track and he ensures that the rest of the teams are also set in tract.

Thank you for listening the first lecture. I hope that this lecture will be supported with the assigned readings as well as the assignments. Please check the course portal for those details and follow it accordingly. Thank you.