Systems Engineering
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Lecture - 13
System Engineering Life Cycle Stages

Again, very warm welcome and good day to all of you. We are in the Systems Engineering course in the MOOCs and I am Dr. Deepu Philip from IIT Kanpur. And what we are talking-going to talk today is dig more deeper into the System Engineering Lifecycle Stages and also compare and contrast different systems engineering process models that are available.

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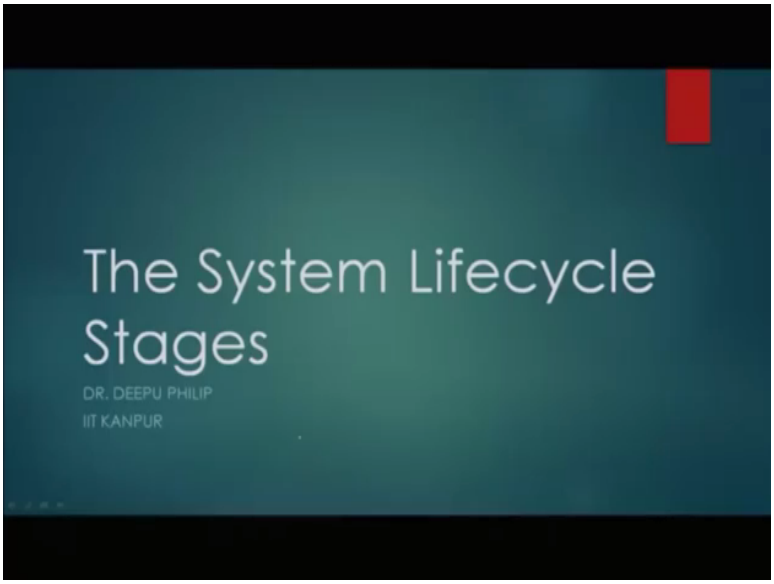

So today's lecture is the Systems Engineering Lifecycle Stages. Though, we will also be looking at different process models towards end of this lecture. And you already seen the previous stuff about the lifecycle and different type of lifecycle models available. And we saw that almost all basic models have the basic stages and phases within that stages phases they are called it in different names nomenclature is used.

So we will see how all these things different basic structure applies to different models.

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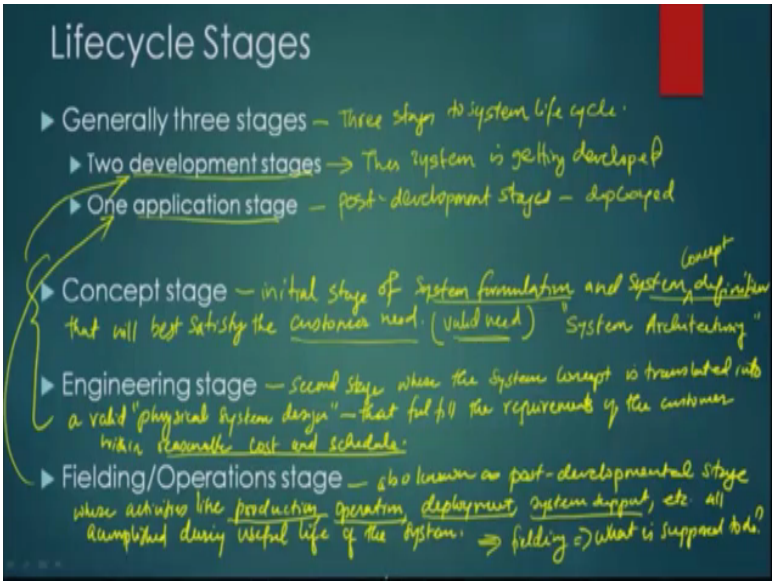

So the lifecycle stages as we seen earlier, is there are generally three stages or there are three stages to system lifecycle. And the two of these are the Development Stages and one is called as Application stage or sometimes also known as the Post Development Stage. So in this case the system is getting developed. Here the system is getting deployed or used so that is why we basically say that these are development stage system.

And this the application or the post development stage or deployment stage of the system. So most of the model will have these three general stages. And the stage-- the first stage is usually called as a concept stage and concept stage we can define it as the-- it is the initial stage of system formulation and system definition. Formulation system definition and system definition that will best satisfy the customer need.

The importance here is that we are talking about the formulation of the system and the definition of the system or system concept definition or you can think about it as a system concept definition. That will best satisfy customer need. The important thing about the customer need is that it should be a valid need. There should be some validity behind the need. And many-- there are certain models this stage is also called as system architecturing.

So when somebody is talking about system architecturing it is the initial stage of the formulation and the concept definition of the system where we are trying to satisfy the valid need of a

customer. The engineering stage is a second stage where the second stage this is again a stage of development so these two are the development stages. Okay. And the second stage where the system concept is translated into a valid physical system design, physical system design.

Again we are talking about the physical system design here because our work is more our discussion is mostly about the products that are to be manufactured -- systems that are manufactured we are not talking too much about soft system or software systems. So the physical system designs, what design is it that fulfill the requirements of the customer within reasonable cost and schedule.

So here we are translating the concept into a physical system design so physical product is being designed and built our engineer which will fulfill the customer requirements within reasonable cost and schedule. So nobody will be interested in designing a system with unreasonable cost and unreasonable schedule. So that is the important aspect of this and then the third phase of the system which is fielding or the operation stage or what we call as the application stage or sometimes also known as post developmental stage as said earlier.

Because, it is after the development of the system the physical development of the system and post development stage where activities like production operations, deployment, system support etcetera all accomplished during useful life of the system. So what we are basically saying here is that the -- their very activities that are associated after the development of system you have to produce a system; you have to build in large quantities.

You have to operate the system in this operation environment; you have deployed the system at various areas various aspects. The system also need support and maintenance aspects etcetera. All of these things are accomplished during the useful life of the system. So here the system is in the, what we call as the Fielding stage, it is doing what it is suppose to do, what he supposes to do.

So the assistance provided here is also one comes under the application stage of the system. So these are the three major stages in almost all systems engineering lifecycle stage-lifecycle

models and you will see different variation and permutation/combination stuff here. So what we will do here is that we will look into detail of these three stages and try to decide for what are the things that constitute these stages and what are the major activities that are part of these stages.

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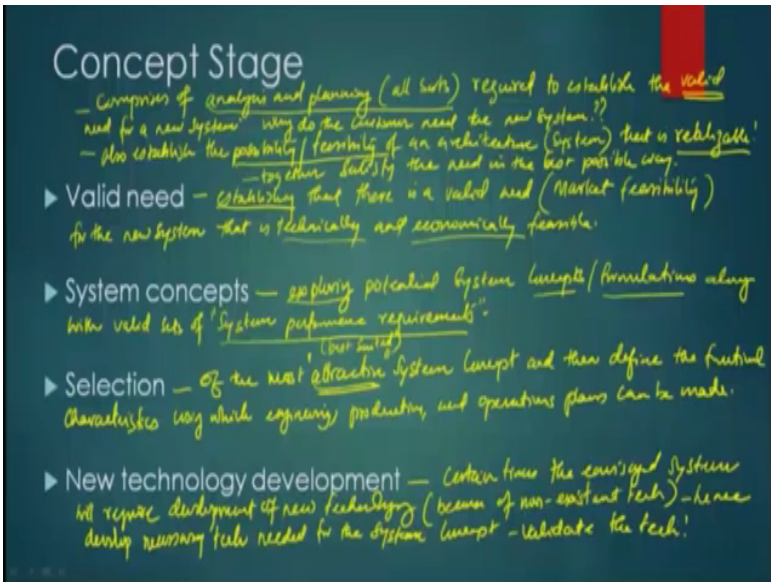

So the concept stage the first thing we need to talk about is the concept stage and if you think about a concept stage it this stage comprises of analysis and planning, so all sort of analysis and planning-- all sorts required to establish the valid need valid is important word “Valid need” for a new system. So the first and foremost thing is it comprises all the analysis and planning required to establish the valid need for a new system.

Why does the so? The question here why do the customer need the new system? This is the important question that we get to answer at this point. But is it just the establish planning and analysis to establish the validity of the need? No, there is some more things that is part of this. Here we also try to do is that you also establish the possibility or feasibility of an architecture, an architecture of who?

An architecture of the system. And that is realizable. So what are we talking about? This point we are also trying to establish the possibility or feasibility of architecture. Is it actually possible to design the system? And that architecture, is it realizable? So those are the two aspects okay.

And in the way that all of these things together satisfy the need in the best possible way. So the concept stage is it comprises of all analysis and planning.

All types of analysis and planning require to establish the valid need of the new system or you are answering the question why do the customer need the new system. And also along with that establishing he needs you are also establishing the possibility or feasibility of an architecture or possibility of a system architecture that is realizable or that can be realized within a reasonable cost and the schedule. So that the customer need can be satisfied in the best possible way.

So the first characteristic we talked about is the “Valid need.” So what is the valid need? So the valid need is so we here is there we establishing that there is a valid need. Or it can also think about as market feasibility. So if you make the product there will be somebody to buy this. And for the new system-- so there is a valid need for the new system that is technically and economically feasible.

So what we are saying here is that you establish the valid need and also establish the technical and economical feasibility of the need. So that is the first aspect of the concept stage, you are establishing the validity of the need. Then we talk about the system concepts, which is the second aspect. So the system concepts here is that you are exploring the- establishing was the first part here you are exploring potential system concept or formulation- system concepts or formulations along with valid sets of system performance requirements.

So here you are exploring multiple concepts multiple potential system concepts or formulations-- concepts or formulations are-- they are like as we said in one of the presentations, all of these are black boxes we are not really detailing the circuit diagrams for the interfaces or anything like that but these are basically the major blocks, building blocks of the system and along with the valid system performances.

So what we are saying here is that the system should be able to meet these performance requirements that is the system concept. So the exploration is the second aspect of the concept stage. Then third aspect of the concept stage is a selection. So here is the selection-- selection of

the most attractive system concept. The attractive term it is not about the beauty or attractiveness of something this about the best fit. So the attractive you can think about it as a best suited kind of a concept.

So the best suited system concept. And then define the functional characteristics. Define the functional characteristics, characteristic of what? Of the attractive system concept, okay using which engineering, production, and operations plans can be made. So here the best suited system concept. So here is a selection process from the explored production system concept you choose the best suited or the attractive system concept.

And then define the functional characteristic of the concept in such a way that the engineering, production and operation plans can be made using the concept definition the selected concept definition that is just created out this. Then, there is another aspect also called as New technology development because certain times, certain times the envisaged system will require development of new technology. Why?

Because, the technology is not existing, because of non-existent technology. So non-existent tech is one of the reason. So certain times envisaged system require new technology. Hence develop necessary technology—necessary tech and tech needed for the system concept and validate the tech. So you just do not develop the new technology you also validate the technology as part of this.

So if a new material is necessary for example when Rolls-Royce is designed the trend series of engine, trend 1000 series of engine they were looking for new materials for the fan blades and that actually required and they finally choose the material as titanium alloys and it required a new manufacturing or fabrication technology to be developed as part of that process. And hence that was developed by Rolls-Royce.

And then they developed it, tested it and proved that the fan blades that are build using the technology; new developed technology is in fact is actually the better than the existing process. So this kind of new technology sometimes would be required as part of the system concept. And

if necessary than that new technology development also become part of the concept stage. So when you go through all these four aspects of the concept stage.

In certain cases, you might only go through two, three certain times you might go through, because sometimes you might not require a new technology development, all the necessary technology is available. So then you will only end up doing the three aspects of it. But anyway within these four aspects bit different permutations and combinations of these four aspects you would be able to come up with the reasonably good concept of the system which is the output of the system concept stage.

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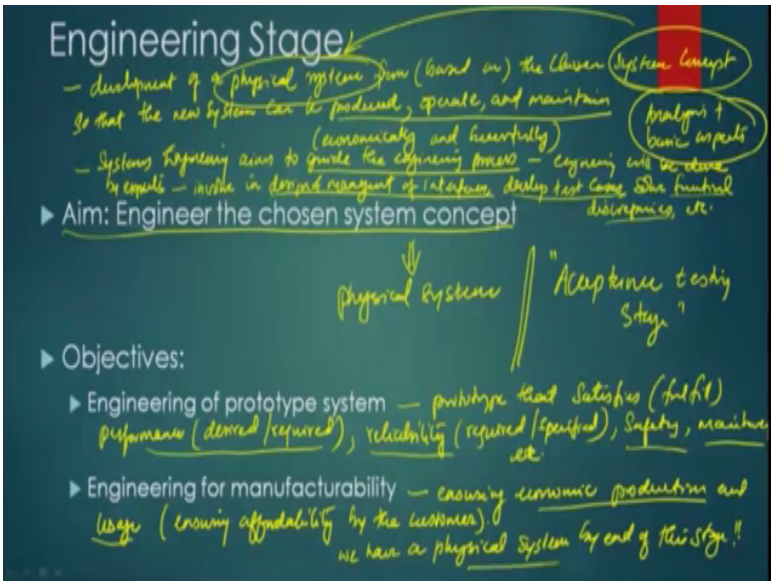

Then comes the Engineering Stage, the second phase after the engineer-- after the system concept. So as I said earlier the aim of it is to engineer the chosen system concept. So the engineering is actually and if you think about it, it is actually the development of a physical system. From where do you develop? From or based on the chosen system concept-- chosen system concept from the previous stage.

So that the new system can be produced we can produce the new system, operate and maintain. How do you do produce, operate and maintain? All these things should done economically and successfully. So the cost economic aspects, economic viability and as well as the successful

aspect of the system is also considered in this case. So you are-- the physical chosen system concept from the previous stage which was more of a analysis + basis aspects.

From here, a physical design a physical system is designed out of this one, so you are creating the physical product that can be produced, operated and maintained that is the engineering the lifecycle model. Or also it should be in order that, the aim of systems engineering-- we have mentioned this earlier aims to guide the engineering process. The engineering activities will be-- why? Because engineering will be done by experts.

The engineering is not the job of system engineering systems, systems engineering job is to guide the engineering process because experts will do the engineering and also to involve in design and management of interfaces, develop test cases and solve discrepancies, solve functional discrepancies etcetera are also aspect of the systems engineering. So the engineering stage, the role of the systems engineering is to guide the engineering process which are conducted by experts in appropriate disciplines.

And also the systems engineer in addition to guiding the engineering will also be involved in the design and management of the interfaces; they will also be involved in the development of the test cases and also solve functional discrepancies. So we look at it the two main objectives that we talked about it is okay. So as we said the chosen system concept kept translated to a physical system, okay. So the objectives is engineering of prototype system.

So when we talk about a prototype system the prototype that satisfies or you can use the word ‘fulfill’ also is fine ‘performance’ what performance? Desire performance or require performance, reliability this also again required reliability or specified reliability and safety, maintenance etcetera. So in this case you are talking about not just designing any prototype.

The prototype that satisfies or fulfill the performance requirements; the performance requirements, liability requirements, safety requirements, maintenances requirements and etcetera. So here the physical system the choice of components, interfaces all those kind of

things comes as part of this. The aim here is to satisfy the requirements. And second aspect is engineering for manufacturability.

So here is also—this is the concept because people different from the design for manufacturing the aspect here is that ensure or ensuring economic, economic production and usage or in a way ensuring affordability by the customer. So you do not want to create a scenario where you design a physical system which is not affordable by the customer. So the affordability the economic production and usage is an important aspect of it.

Or in a way the engineering stage that is why sometimes we call this as the 'Acceptance testing stage.' So whatever the concept it is when you translate into a physical product then it should be acceptable to the customer, so that part the acceptance to the customer because the customer will only accept it if it is economically feasible to him to produce and use it otherwise customer would say that is not -- something that I am not interested in.

Because I do not know have the financial resources to maintain this. So that is the second aspects. So, we now seen both of the pre-development phase. This is where actually by end of this stage we have a physical system by end of this stage; that is the important aspect of this lifecycle stage.

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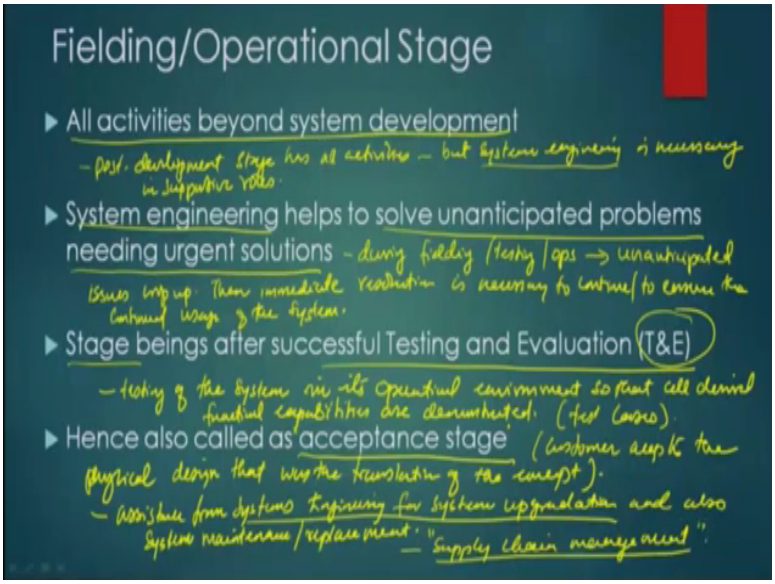

Then the third part we talk about is a Fielding and the Operational stage. The fielding and the operational stage this in a broad sense in a simple sense it is all activities that are beyond system developed. So you are talking about everything that is after the system development. So what are the major things here?

So the post developments stage, some people call this is post development stage or some certain models called as a post development stage has all activities beyond system development. But systems engineering is necessary. Why it is necessary? Because it is necessary in supportive role. There are certain aspects after the development of the system where systems engineering still needs to be involved in the post development stages of the system during the operational things.

The first and foremost thing is systems engineering helps to solve unanticipated problems requiring urgent solutions. So during fielding, or testing or operations unanticipated issues crop up. Then immediate resolution is necessary to continue or to ensure the continued usage of the system. We will discuss this point in little elaboration using an example-- real-life example later during this presentation.

Because it is important to stress these aspects because many of times people do thing that the fielding and operational stages there all of the systems engineering is not there but systems engineering do apply a significant or a major role in this process and also this is a stage at which successful testing and evaluation happens. So the successful testing and evaluation means testing of the system in its operational environment.

So that all desired functional capabilities are demonstrated. So as we mentioned in the previous slide the test cases that are developed by systems engineer comes in handy at this point where the successful testing and evaluation the T and E of the system were the user is taking the prototype testing it putting into different test cases and seeing the performance of system and getting satisfied that all the functional requirements specified by the user is fulfilled by the designed system or the physical design of the system.

Hence that is why it is also called as the ‘Acceptance stage’ by certain people or certain model there are certain systems engineering model developers because this is where the customer accepts the physical design that was the translation of the concept of the system concept. So we also-- another aspect of this is we should also thing about it is the – this stage also require assistance from systems engineering for one important thing which is called as system upgradation.

Systems engineering for system upgradation and also system maintenance replacement. So in addition to the testing the acceptance testing of the system the systems engineering help is also needed for upgradation of system because some of the things that might when the user uses this or well this is really good but it has taken some time to develop the system because remember we already told that all systems engineering projects are usually long projects because of the complexity of the system involved.

We are talking about development the system or systems or complex systems. So it is not a one or two-year project it probably be as long as 5-8 year long project. So during that project the technology would have advanced and when the system actually come up the user feels that okay this is a new thing that need to be happen so the system also the current system that need to be developed need to be upgraded to suit that.

That will be one aspect of the system engineering where systems engineers will also help. The last and final aspect will also be the Supply Chain Management. The systems engineering or systems engineer help is required in also maintaining the supply chain to ensure that the product fulfills its operational lifecycle. So that is also needed because during the lifecycle parts need to be changed.

Things has to be maintained all that requires a dedicated supply chain or a smooth functioning supply chain that is required which should also be which is also the responsibility of the systems engineer to design the supply chain and make the user aware of such a supply chain so the user when he use when user utilize the system-- can utilize as a supply chain to ensure that the system continues to operate successfully throughout its entire designed lifecycle.

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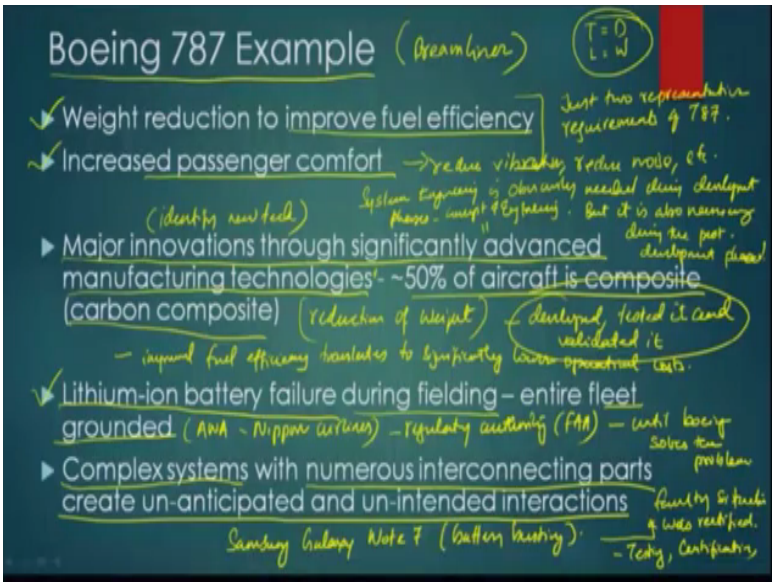

So, let us talk about an example to discuss about these aspects. The Boeing 787 or what is commonly known as the Dreamliner example. There is—it is quite a long big example but what we will try to do is we will try to take some the simple salient points and try to establish the importance of systems engineering and how the systems engineering did actually help after the product was fielded.

So there are many aims. So these are just to representative requirements of 787. I just took this just to demonstrate things. There are so many multiple many, many, many requirements that are part of the 787 design. But two important things are we talked about here it was the weight reduction to improve the fuel efficiency.

So the Boeing really wanted to reduce the weight of the aircraft because for anybody who is in Aerospace engineering would know that any aircraft that need to fly or flies over any body that flies, you know that the thrust should be equal to drag and life should be equal to weight. So if the weight reduces then the requirement of the lift also reduces. When the requirement of the lift reduces then the amount of thrust require to fly also reduces.

So the aim was to actually create an aircraft that has less thrust requirement but can carry thrust requirement due to its less structural weight. So that you can get a better fuel efficiency out of it

or improve fuel efficiency out of it. And second goal was to increase the passenger comfort or comfort in the sense that reduce vibrations, reduce noise etcetera. These are the some of the aspects of the two aspects of the Boeing Dreamliner 787.

There were so many other more aspects but we are not talking about, we just two as an example. So one thing when they started designing and developing this they found out that he technology is not there to actually develop the airframe using composite materials. So major innovations through significantly advanced manufacturing technologies were required, so this is where we talk about the identify new tech that is part of the concept phase.

Figure out that is the aircraft has to be built up about 50% of the aircraft is to be composite or carbon composite based aircraft for why? For what? Reducing the weight, the reduction of weight. This was the option that Boeing took because if you want to reduce the weight then the significant portion the aircraft need to be build using composites. And if you have to build aircraft using composite you have to build advanced manufacturing technologies that were not available at that point.

So Boeing invested in developing the new advanced manufacturing technology to realize an aircraft where approximately 50% of the aircraft is composite based. So this is where-- then they just did not develop the manufacturing stuff they developed it tested it and validated it. The new manufacturing process has been developed, tested and validated. So that was one aspect of how the new technology gets developed as part of the concept phase.

But then the Dreamliner came out it became a big head lot of companies ordered significant amount of large ordering happen because the improved fuel efficiency translates to significantly lower operational cost. So everybody felt that Boeing 787 Dreamliner is going to be a big hit, it is going to revolutionize the entire-- the way in which aviation sector is going to perform, so it was - it setup new benchmark.

Everything was going great and at the one point of time the problem that almost everybody anybody who deal with engineering might have heard about this the Lithium-ion battery failure

during fielding of the 787 Dreamliner. You might have heard about the case of ANA or Nippon airlines the Japanese airlines where the batteries busted during flight creating significant, significantly dangerous situation for the passengers.

So the Lithium-ion batteries that were used in Dreamliner 787 started behaving then and when multiple aircrafts had the issues battery started busting then the FAA the regulatory authority like FAA and all issued warning that the fleet needs to be grounded. So anybody who was operating the Dreamliner 787 had to ground the fleet. Up to how far? Until Boeing solves the problem.

So then the Boeing system called up on a systems engineering again to figure out what happen and obviously we know that if you are engineering a complex system like an aircraft like Dreamliner there will be so many numerous interconnecting parts myriads of interconnecting parts and when all these parts are interconnected there are many parts are interconnecting then would try to – you would think that you taken care of all the cases.

But many a times there will be unanticipated and unintended interactions between the systems. So the system engineers might have developed test cases for validating things but at a one particular point where a specific combination of temperature pressure and other aspects came in or a condensation came in or moisture level came in the batteries behaved variedly.

So one of the major reason in this point, or the reason for this failure was that the interactions or interconnecting, interconnection between the battery and the complex the system the power management system of Dreamliner was causing the problem. And same system-- same behavior was also found in another example would be Samsung Galaxy Note 7 were the battery busting was another issue.

So anyway Boeing got into the rack together and got the systems engineers to come up with a alternate design of interface; come up with better choices of batteries and then the faulty situation where-- was rectified. Once the rectification happened testing continued then certification again was done and then the fleets where back to normal.

So this is a particular situation where the systems engineering was called in again to assess the fielding of the fleet or the operation of the Dreamliner 787 during its what we call as the deployment phase or when it is actually fielded. So it the takeaway from this example is that it is not just the-- so you can think about this way systems engineering is obviously needed during development phases the two development phases the concept phase and the engineering phases.

But it is also necessary during the post development phase or the deployment phase in the system. So that is also an important takeaway of this lecture or of this example is that any system any complex in your engineer you-- it will be almost impossible to develop test cases to test and validate every aspects of the system.

And given the fact that Boeing designed Dreamliner 787 and there was only one major issue with the battery when one minor issue about the door or issues with the hinges of the door other than that having just two issues that need to be sorted out in the design and develop in such a complex system shows the importance or the significant of going through a good sound systems engineering approach.

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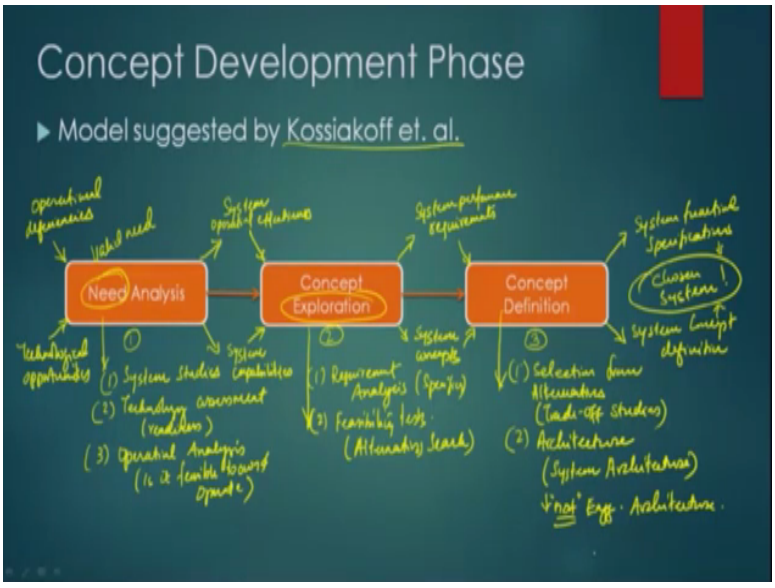

So we will look into the further details of the systems the concept development phase which is model is proposed by Kossiakoff et al; and there would specified different aspects of which also gives you very good overview of what are the inputs and output of each of the processes of the

system. So the first phase which is a concept development phase as we said earlier has three important steps in it.

The need analysis, which is the first step, second step is the concept exploration and third one is the definition. So, the need analysis ask typically two inputs. The first input comes from the operational deficiencies that is the first aspect. The second aspect comes from the technological opportunities. So the two inputs the technological advancement give you a new option. So as I said earlier how nuclear submarines arrived because it is a technology advancement in miniaturizing nuclear reactors suggested the feasibility of developing nuclear submarines.

Similarly, also the operational deficiencies like an example of that would be India looking for medium range fighters because of the depleting field, sorry, depleting fleet conditions of the air force as forced India to actually look for “Stop by arrangement” so there is an operational deficiency. So sometimes operation deficiencies sometimes a technology advancement sometimes both of them put together creates a need or establish a so both of these.

Here you are talking about the need is a valid need for the customer. So, once that comes in then from there multiple things happen within this. So what are the major multiple things happen within this? The first one will be the systems studies so multiple studies will be undertaken to study what are the possible system then the second one will be the technology assessments.

So here the readiness-- technology readiness is being assessed whether technology is available or is a new technology need to be developed all those aspects comes out here. And then the third aspect will be operational analysis. So here is it feasible to own and operate for the customer. So those aspects basically gets designed here. So as I said earlier these are all analysis, the concept phase is mostly dealing with analysis aspects of the system. From here we get two outputs.

The first output we can call it has System operational effectiveness and the second aspect will be the system capabilities. So the output of the need analysis will be system operational effectiveness and system capabilities (()) (44:58**)** and which will become the input to the next

phase which is the concept exploration. So the concept exploration has multiple aspects as part of this, the first aspect would be the requirement analysis here the specifics are build.

And the second aspect would be the feasibility test. So the-- here we are actually looking at multiple options so here is also another way to think about it is alternative search. So what are the other alternatives available to the system or to fulfilling the need what are the possible options out of it. And we have two output out of this the first output is called as the system performance requirements. What are the performance requirements?

Not just the-- specific performance requirements so like for example in the case of Dreamliner what we talked about one of the performance requirement will be 50% of the aircraft will be build using composite resulting in a 20% less structural weight or it could be like because of the less structural weight the thrust requirement is reduced by 10% resulting in a fuel efficient increase of 3% so something like that.

Performance requirement will get actually crystallized as part of this and in the second aspect will be system concepts. Multiple system concepts gets derived as part of this. So here you are exploring the exploration is the big word here. Once the exploration happens and the performance requirements comes out which becomes the input to the third phase which is a concept definition and the concept definition is where basically two aspects happen.

Selection from alternatives or you can think about it has trade of studies. How are you doing the different trade-off among different alternatives the positives and negatives are all possible alternate system configuration are evaluated so that an appropriate system can be chosen out of that. Then the second aspects of this will be the architecture. Not talking about the it is called as a system architecture.

Please remember that this not engineering architecture “Not” is a keyword not an engineering architecture. But here-- and one of the earlier presentations I mentioned that it is mostly related to the block diagrams and interconnectivity and those kinds of aspects not just specifically

choosing what will be the specific component that will go and do it. Sometimes some components information is available but not necessarily.

Because lot the component choices and another thing will be the job of their experts. Not the job of the systems engineer at this phase. So from here we get two outputs two major outputs comes out of this. And the two major outputs of the system are system functional specifications and system concept definition. So here you can think about it as a chosen system. So one single system is chosen here.

And then, the functional specification of that chosen system and as well as the concept of that chosen system gets specified as part of the output of the stage. So summing up again the three phases has the analysis of the needs where the valid need - validity need of the customer is established here and from there the required capability of the system and the operational effectiveness are established which goes into exploration where multiple systems are multiple alternate explored their aspects are listed out from where the system performance requirements.

And the concepts both of them come out of output of it which gets such input in to the third stage where the appropriate choice of the system is done or as specific system is chosen from there and then the functional specifications of the chosen design and the concept definition are both part of comes out of the output of this concept development phase.

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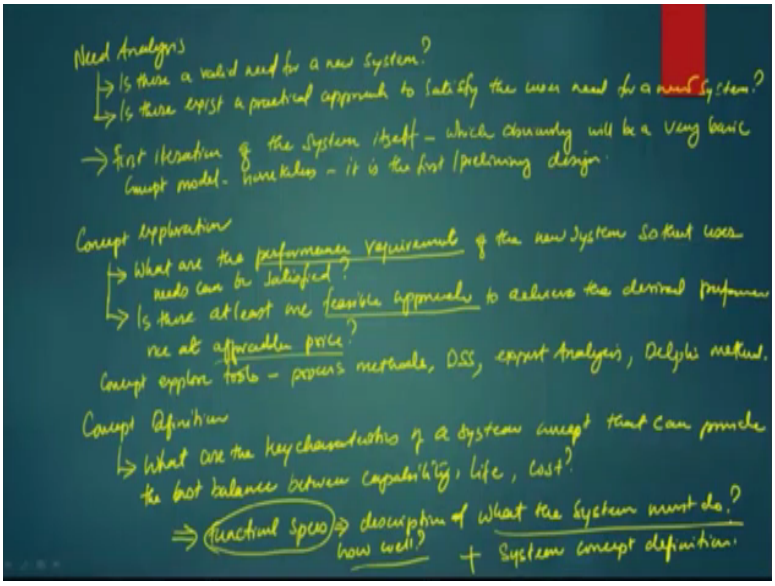

Also we should understand the fact that when we talk about need analysis initially what do we do there? So, need to remember these two important questions. Is there a valid need for a new system? This question is the first and foremost most important aspects that becomes a part of the need analysis. The second important question is the, is there exist a practical approach to satisfy the user need, user need for a new system.

So the two important aspects that gets covered in the need analysis is either a validity of the need for a new system, does the customer require a new system and is there a practical approach available to satisfy the user need for a new system. Is it feasible? Can it be made? Can it be build? So in a way the output of this is the first iteration of the system itself which obviously will be a very basic concept model nonetheless it is the first or preliminary design.

So that is what the importance of the need analysis that comes out. Then we also talked about concept exploration where these things need to be kept in mind. In concept exploration, again there are two questions that are important. The major question is, what are the performance requirement of the new system of the new system so that user needs can be satisfied? That is the first question.

The second question is, is there at least one feasible approach to achieve the desire performance at affordable cost or at affordable price. So the two aspects, you looking at what are the possible

options, what are the performance requirements of the new systems so that the user needs can be fulfilled. And what are the feasible approaches to achieve the desire performance at an affordable price. So that will be the aspect of the concept exploration.

And-- the some of the tools that are used in concept exploration, so the concept explore tools involved various process methods, decision support systems, experts, analysis, also Delphi method etcetera are all part of this, so multiple tools are used so that different feasible approaches can be got through so you are exploring the concepts. Then comes the definition the concept definition the third aspect.

And here the major question, the single question that gets answered here is what are the key characteristics of a system or of the system concept that can provide the best balance-- we earlier told about the systems engineering is a balancing act the best balance between capability-- capability of the system, capability life of the system and cost of the system. So this is the major questions that get answered.

So the functional specs okay, so here in this regard is the-- as we said earlier the output of this whole process will be the functional specs or specifications which means it is a description of what the system must do and how well is the aspect. So the functional specs basically provide at the end of this whole exercise what the system must do and how well is specified as part of this. And obviously as plus system definition itself system concept definition itself also is an output of this stage. Thank you.