Systems Engineering
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Lecture – 14.2
Requirement Analysis (Continued)

So further getting into the requirement analysis, we should look into a little bit more detail into what the requirement analysis.

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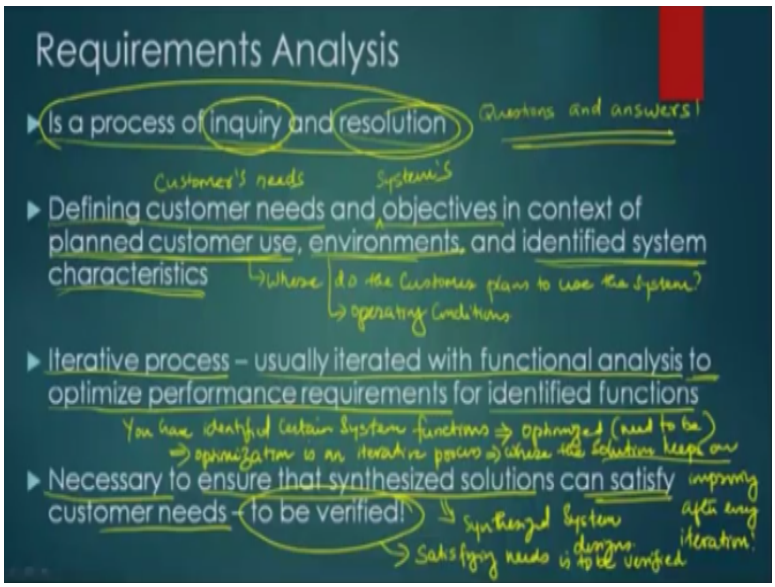

So the first and foremost thing that we need to understand here is, it is a process of enquiry and resolution. Enquiry and resolution in a simplest include English form it is questions and answers. So we keep on asking questions, we keep on finding the answer. So it is a process of enquiry and resolution, you enquire about something you keep looking for it, you until you find a satisfactory answer until you resolve it satisfactorily, then the process continues.

So the requirement analysis is a process of enquiry and resolution or questions and answers. So what does it entails to. So the defining the customer needs and objectives in context of planned customer use, environments and identified system characteristics. So you are defining the needs of the customer as we said earlier it is the customer's needs, customer's need.

So we are defining those needs and objectives, the objectives, whose objectives, the systems objectives. The customer's needs and the system objectives are defined in the context of

planned customer use. So this question is like where do the customer plan to use the system. This is the one aspect.

The planned customer usage of the system, the environment, you can think about it as operating conditions and then identified system characteristics, certain specific characteristics, the system that are identified as part of the customer needs and the system's objectives. When we discuss the UAV system in detail as a case study, we will get a cross this system characteristics identification.

Also, as we said earlier, it is an iterative process, iteration means it is a repeated process. What is the iteration in this, it is usually iterated with function and analysis, you are iterating with a functional analysis. For what, why do you need to iterate, the iteration is to optimize the performance requirements for identified system functions. So you have identified certain system functions. These system functions need to be optimized.

So this functions need to be optimized then you need to iteratively analyse these functions. So the optimization is an iterative process where the solution keeps on improving after every iteration. So the aim is that you iterate, you repeat, you continuously repeat the process of functional analysis. To ensure that each iteration, the solution, the system solution that you are proposing or the design solution that you are proposing is improving after every iteration.

So each iteration gives you a better version of the system that is also one aspect of the requirement analysis and all of these are necessary, they are needed to ensure that the system synthesized solutions or synthesized system designs. They all of those designs can satisfy customer needs or you need to verify, so this has be satisfying needs is to be verified or verifiable.

So the verification here is that whatever the design of the system that is been synthesized, it need to be verified to ensure that it needs the customer needs or it satisfies the customer needs within this specified constraints. So as I said earlier, just to recap it is process of enquiry and resolution or questions and answers. Keep on asking these questions, iteratively with aim to improve the system at each iteration.

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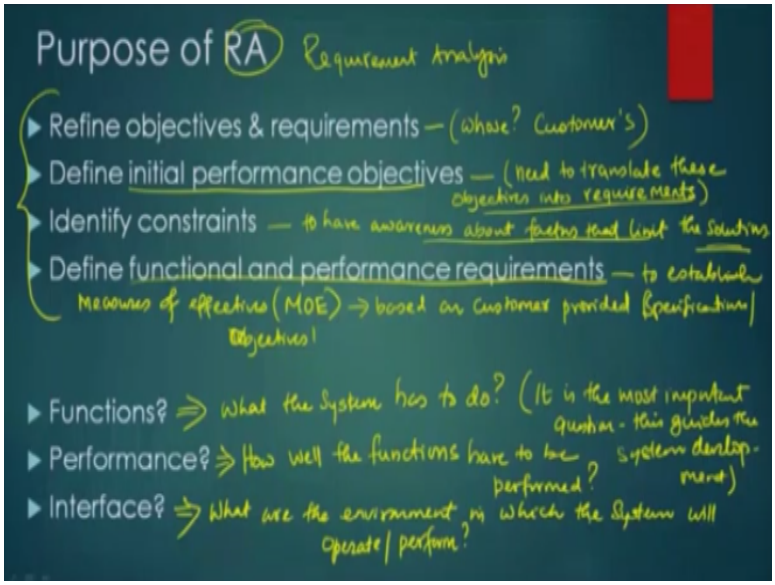

So the purpose of requirement analysis, we basically as mentioned this, as we write it down much more cleanly in a much clarified way, then the purpose of RA, RA stands of requirement analysis. The first and foremost thing is, it refine objective and requirements, so whose objectives and requirements, obviously customer's. So the aim is to refine customer's objectives and requirements such the first purpose, or the first reason why we do requirement analysis.

Second is define initial performance objectives and why do we need to define initial performance objectives because we need to translate these objectives, these objectives needs to be translated into requirements, specifically measurable requirements. As we seen earlier these should be quantifiable, these should be measureable, not using a loosely typed word like sufficient, it is not enough.

It should be a number that can be as much as possible quantifiable, verifiable number is what we are looking for as much as possible. So the initial performance objectives are defined in order to translate them into objectives, these objectives needs to be translated into requirements. Then the other aspect is identified the constraints. So why do we need to identify the constraints to have awareness about factors that limit the solutions.

So whatever design solutions that we propose, design solutions that are proposed, we need to be aware of the factors that are limiting them or the factors that are constraining these design solutions, that is also another purpose of requirement analysis and last part is define functional and performance requirements. Why do we need to define functional and

performance requirements to establish measures of effectiveness.

People call this as MOE, Measures of Effectiveness, based on customer provided specifications or in a better word requirements or objectives, let us not use the word requirement, let us use the word objectives. So here we are establishing Measures of Effectiveness, MOE is based on the customer provides specs or objectives.

So that the functional and the performance requirements can be quantified or verified okay, so that the aspect also need to be a taken care of. So these four things to a large extent helps you for the purpose of requirement analysis. So obviously, some question is the functions as we said earlier, function is an important question. The question asked here is what the system has to do.

This is a very important question because it is the most important question. This guides the system development. The system development is guided by this question, the function, what the system has to do. So the first and foremost thing is to understand the function of the system, then is the performance. The question here is how well the functions, how good or how well the functions have to be performed. How will the system has to perform these functions. So this is the performance question about the system. Third one is the interfaces.

The interface is what are the environment or environment in which the system will operate or perform. So this is basically understanding about the situations or environment within which the system will perform or the system is going to accomplish its function, whatever the system has to do, how will it do and where will it do, what are the environment within which it will do. So this is actually in a nutshell, the requirement analysis. Many at times, the equipment analysis can be very well expressed as a schematic.

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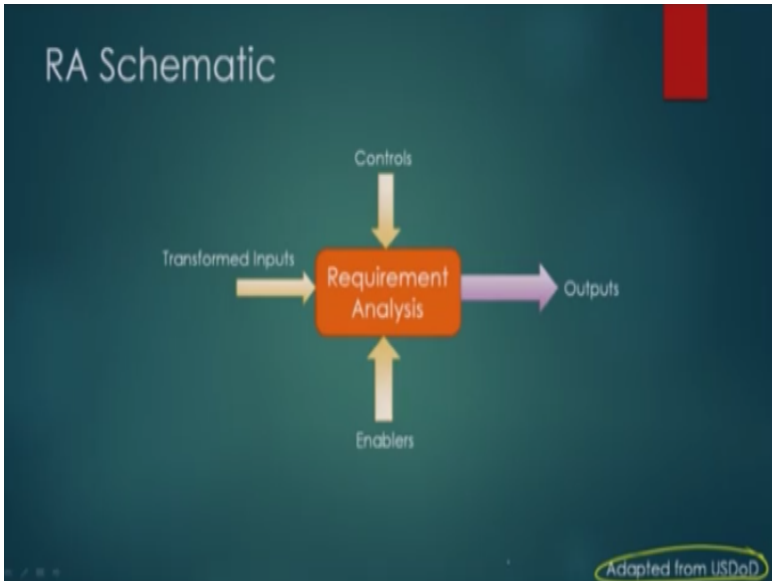

And this schematic was first proposed by the US Department of Defence in their model. We have actually seen a brief summary of the US Department of Defence model in the earlier presentations and we have also identified that there is a requirement analysis from their there is a functional and analysis and after that there is a designs synthesis.

All there are three loops and then there is a verification loop where after the design synthesis, the design is verified with the requirements, I hope you remember that model and there is a system control, the system's engineering process which actually does the monitoring or controlling of all the three loops to ensure that there is sufficient depth and breadth within which when the initial phases of the system is being designed is being taken care off.

So if you forget that I request you to please go back to the previous slides and read it again and refresh your memory. So this is the beginning of the requirement analysis part of it, where the requirement analysis, it kind of takes three inputs. The transformed input is one, second is the control and third is enablers, all three put together to give you the output. So it is one plus two plus three will give you the output.

So that is the way, we look at this in this model. So what are the transformed inputs in this case. So let's talk about the transformed inputs. So these transformed inputs if we write what it is, as we said earlier, it is a comprehensive set of inputs. Why it is comprehensive because it define both system products and system processes. So it is not just define the product, it does not define the system.

It also defines the processes, how are you going to realise the system or how certain aspects of the system is going to be realised built, manufactured, supported, all those aspects, the processes that are related in realising the system are also listed out. That is why it is a comprehensive set of inputs and these are transformed. Transformed means they are converted from the user requirements.

So the customer requirements, they get transformed into this inputs. So the customer requirement is one of them then the Measures of Effectiveness is another one, Measures of Effectiveness as we seen earlier, then the maintenance aspect which is a part of the process also and a product aspect also is there, then the life cycle functions, we have seen the total life cycle functions of the system and we also talked about prior system development knowledge.

So you might have done this exercise earlier. You might have performed of a similar system development and the knowledge that you acquired from those development that is also included in part of this transformed inputs. So all of these become the set one input, which are the transformed inputs of the system. Then the controls, the control aspect of the system is unique because this includes this like laws.

It could be control laws or it could be law of the land or global law or something like that like you will, when you are working on developing a system or a weapon system, if you are signed a treaty that there will be no chemical weapon development, then obviously yes you are going to abide by that law or that treaty or whatever it is, so that is one aspect. Second aspect is the organisational policies and procedures.

So like an example is when a rifles are developed or what we call it as automatic rifles are developed. There might be an organisational policy in the department in a particular military saying that it should be suitable for both left-handed and right-handed usage, which mandates that the cartridge ejector system should be switched, you should be able to switch the cartridge ejectable system to suite the left hand usage as well as the right hand usage.

So the person, who is right-handed is holding the rifle like this, then the cartridge should be eject the side, but if the left hand side person is holding the gun like this then the cartridge should eject. It should eject away from the body. So the design should be done in such a way that both left-handed and right-handed usage of the assault rifle should be done for. So that is

an organisational policy and procedure.

So that is a control that is put on to the development of the system. Similarly, another aspect is the military specs. We are talking about the military specs before here specifically because lot of the systems engineering complicated system developments are supported or funded by military funds. So hence a lot of this development comes into military specs.

So some times the, some of the systems are developed like somebody is working on developing autopilot for UAV. It is probably better that the autopilot has a, it meets a military standard, some military standard because the largest customer who is going to use the autopilot might be military. So if you do not develop it to the military specs, then you are excluding your large set of possible customers.

Hence, military specs usually becomes a control in the development of a system. Similarly, another aspect is the environment. The environment within which you are going to use the system might also be another control aspect, a limiting aspect of it. So like, for example, is when the European system, European community came together and said that we are going to eliminate the usage of gasoline vehicles by 2025 something like that.

They specified a time. Then the system have been developed or researches has been put in place to actually develop electrical systems, which will replace the ongoing gasoline based vehicles propulsion systems in Europe. So these kinds of thing, so sometimes operational environment or environmental conditions are put into place will also form a control on the development of the system, could be a limiting as well as it could be a liberating fact as well.

Then we talk about the technology base. May be people might be talking about setting of a colony in mars at this point. But we might not have that complete technological how to realise it. So hence, the current available technological base, so this is the available technological base, is usually one of the control, which the technology might not have been matured to a level where the entire wish list of the customer might not be realizable at this point.

So hence that becomes one of the control aspect of the system. So that these whole things put together becomes a control side of the input to the requirement analysis, then we talk about

the enablers, the enablers are some unique things. First example is the multidisciplinary product teams.

This is a very important aspect, we will discuss a little bit more about in this case because any development of a system who is the person who knows the maximum about the system, the most about the system. The answer is the operator. The person who is going to operate the system, knows the best or the maximum about the system. Hence, it is better that the operator who knows in detail about the operational deployment should be a part of the team.

This is very, very important because unless you do not have the customer taken into confidence from the beginning itself when you are doing the requirement analysis, it is imperative that the person who is finally going to use the system in the field need to be part of the team, should be part of the multidisciplinary team. Remember, I told earlier, this is also called as the operational person, is also called as the key customer.

So this is where the person becomes part of the interdisciplinary team. Then the other aspect that is important to this is the decision database. We need to keep track of why certain decisions are being taken and what are the reasons behind it, because the later down the road, the revisions, lifecycle upgrades, changes, modifications all those things about this system, these decisions will be required.

So a database is required of the decisions and also a database of requirement is also necessary, requirement database why because certain times, not all requirements, the system designer might not be able to fulfil all those requirements. So certain things which are not a high priority requirement might get delayed on the road. For example, when the initially a fighter jet is developed. There might not be too much emphasis on the development of a naval variant or a variant of the aircraft that can be launched from an aircraft carrier.

It might not be actually thought through in the beginning stage. But once the land based system has been developed and reached a sufficient level of maturity then the design has been iterated, where this naval variant usually gets pushed up and then additional modifications are made to the design to accommodate the idiosyncrasies of development of a naval variant, which actually requires a catapult based launching and pretty much arrestor based landing system.

So it puts a lot more different heavy stresses on their frame hence, there are sufficient strengthening another aspects are required in developing that aircraft. So but since you have already proven the land based system, the development of the carrier based system becomes much more easy because other part of the system is already proven.

So at that point, if you have a requirement database and where these details are sorted out, when the time comes for the development of the naval variant, then you need to go back to the database and pull the data out of that and finally also is the, we need to talk about the system analysis and control here. Those aspect of the system development is also being part of the enablers because the system analysis and control, they say he is the one that actually helps you or guides the entire development process.

So as the same time the requirements are being analysed, requirements are being sorted out or crystallised or we are making them in specific order when the documents are being prepared. It is a good idea to actually also develop the how the development process will be managed, that aspect also need to be a specified out and from there we get what we call as the output out of this.

So the RA output, the requirement analysis output typically comes in three forms out of this, the three aspects of the output. Many of the software development systems, they have much more larger subdivisions of this, but generally you can group it all of these things can do three broader aspects.

So we will now see what are those three outputs that comes out of the requirement analysis. Before talking about that we also need to talk about the questions. What are the main requirement analysis question that happens. In addition to the questions that we were talking about when we were identifying the customer needs and objectives.

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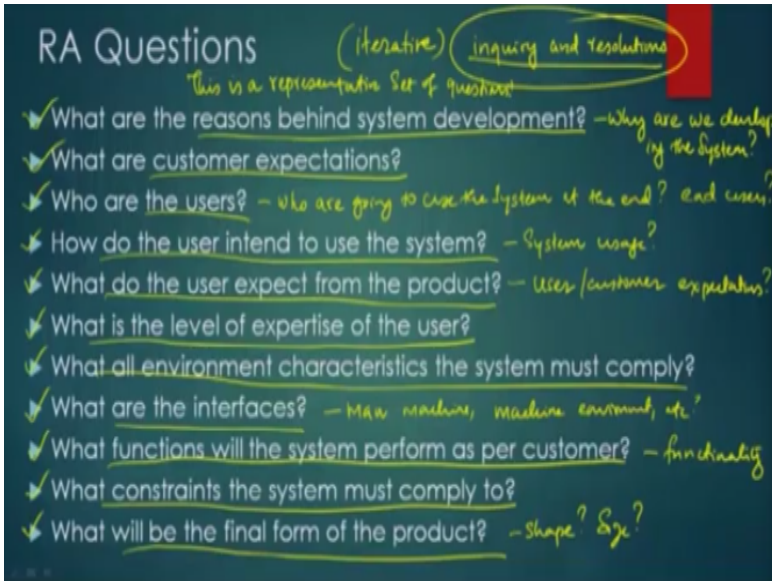

These are the questions that further allow us to drill down, remember the process is iterative. It is a process of enquiry and resolution. So you keep on asking questions and you keep on finding the resolutions to those questions. So the questions are, what are the reasons behind the system development or the question here is why are we developing the system. The motivation behind developing of the system is what is being asked.

There are many different variations of this questions that you can see. So I am proposing just general set of questions that it depending upon which book, which handbook, which model that you refer to, these questions vary, but the essence of the questions remain the same. The purpose, the essence, the purpose of the questions remains the same. What are the customer expectation that becomes a second question.

We have already seen what a customer expectation is. Who are the users or in a way some people asked this question who are going to use the system at the end. Some people ask the question who are the end users. There are many variations of this question you can see. But the idea is who are the users, we are trying to identify the users. How the user intend to use a system okay. Here we are talking about the system usage.

You will see many other variations of this question again but how do the user intent to use the system. The way the user will put the system into use, is what we are trying to understand here. What do the user expect from the product. Some people call this as user or customer expectation.

But here I am trying to write these questions as generically as possible because you can, if you understand the essence of the question, the various forms in which a question asked depending upon which model you are referred to, you can understand and ask the appropriate question accordingly. Then another question is the, what is the level of expertise of the user. How good the user, how much expertise the user have in using the system.

What all environment characteristics the system has comply to. So this is again the environmental aspects to system need to be compliance with, then the interfaces, interfaces here is the, the man, machine, the machines, environment etc. So many variations of these questions again you will see similarly what functions will the system performs as per customer.

So here again the functionality is some people call this also so what are the functions specifically we have already seen the functions analysis but you could have drilled down, we might have derived new functions out of it, we might have translated their requirements into a specific derived requirement which might have translated transformed it in, so it need to be ensured that the transformed or the derived requirements still do meet the original wish of the customer.

Then what are the constraints a system might comply to. The constraints within which the system operates that needs to be again thought through and what will be the final form of the product the shape or the size, the physical aspects of the product, those aspects are also thought through in this.

So all these questions that we see now which is part of the development, the form of the product, compliances, the customer wish list, the environmental characteristics, expectations, intended usage all these kind of things. As we said earlier, it is enquiry and resolutions, you keep asking all these questions.

The more time you spend here in clarifying things, the better, the lesser time you will actually spend in developing the product. So this is not just the comprehensive list of questions. There are way much more questions you can ask, but this is the beginning. So this is a representative set of questions. So that is also need to be thought through.

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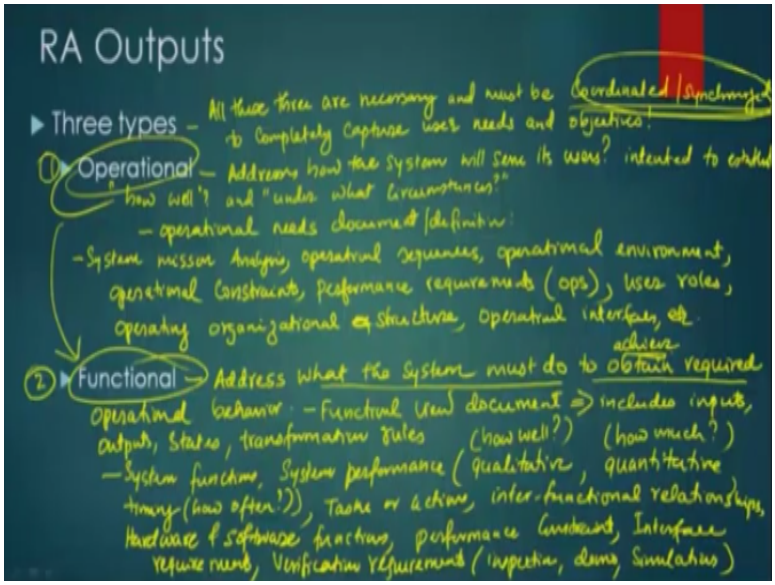

So then we talked about the outputs. We told that there are three outputs that comes out of the requirement analysis in the previous diagram. So what are the three types of outputs. The outputs are the first one being is operational output okay and remember that all these three are necessary and must be coordinated or synchronised is another word that you can use, synchronised to completely capture user needs and objectives.

So there can be more than these three, but broadly speaking all the outputs of the requirement analysis can be classified broadly into three categories and all the three are necessary and they must be coordinated. Coordinated or synchronised because when you come up with the operational output or the operational requirement output or the form or document, then what whatever you specify there, it should be in sync with the functional aspect.

It should also be in sync with the physical aspect that we are talking about. So we will see what are the salient features of all the three cases and why are they important, but remember this, they need to be coordinated and synchronised as part of this requirement analysis. So the operational aspect, what does it do, it addresses how the system will serve its users.

This will be the question and it is, so the intention or intended to establish how well and under what circumstances. These two things are established as part of this operational document. And many at times people call this as the operational needs document and it is also called as operational need definition document also. That can also be here and it contains things like system machine analysis where analysing the system missions, then we talk about the operational sequences.

The sequence in which the operation of the system happens, then we talk about the operational environments, then we also talk about the operational constraints. And we talk about the performance requirements, obviously the operational performance requirements, is the ops performance requirements. Then we talk about the user roles, the role of this user in this. We talk about the operating organizational structure.

Which organization will operate this and what is the structure of this organisation, that is an important aspect. Then operational interfaces etc. So it is a comprehensive document where many almost all aspects, not almost, every aspect related to the operational needs of the system are documented as part of this. So that is the first part. The second part is the functional part where the prime aim is to address what the system must do to obtain required operational behaviour.

This is called as the functional view document many at times, which talks about what the system must do to obtain or achieve required operational behaviour. So here we it includes, this document includes inputs, outputs, states of the system and transformation rules. How does the system transform from one state to another that rules.

All these things are specified in this document and it has obviously system functions, detailing of what are the functions of the systems. It is also details about system performance. Here it is detailed in three different aspects, the three different aspects are qualitative first, the qualitative is the question of how well that is the question, then we have is quantitative. The quantitative asks the question how much and then the last aspect is the timing.

A timing asks the question how often. So these aspects are part of the system performance. Then it is to be, it also contains a list of tasks or actions, the system need to perform. It also contains the inter-functional relationships. It also contains what we call as hardware and software functions then performance constraints. It also will contain interface requirements.

And it will also contain validation or verification requirements. So this would involve things like inspection, then testing, demo, then stimulation etc. So this comprehensive documentation will comprise of the functional aspects of the system. So when you talk about the operational constraints. This is why we talked about these should be coordinated or

synchronized because you can see that if you make some changes here in this operational aspect of the document.

There corresponding changes should also be reflected in the functional aspect of the document. Otherwise the entire development of the system will go in a synchronized fashion. And finally the end product that is realized might not satisfy the requirements of the user. And the final aspect of it is the physical aspect of the system.

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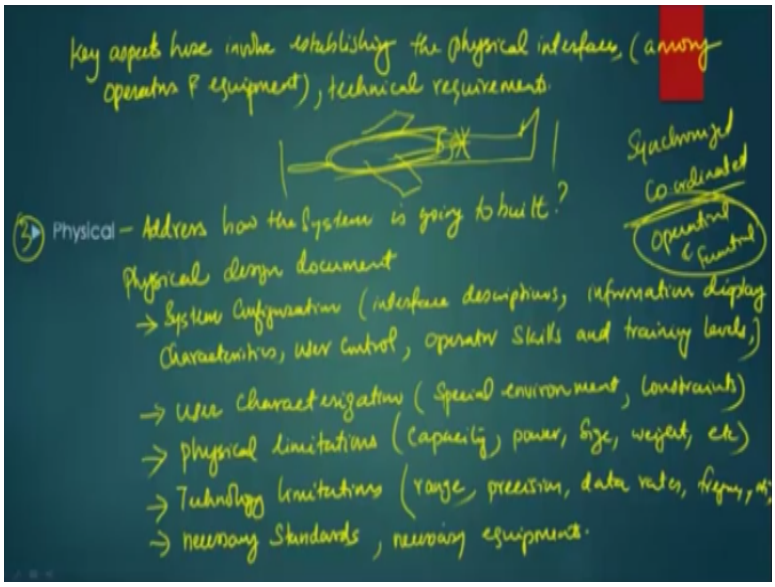

So the physical aspect of the system here what it does is we address what we call as how the system is build. System is going to be build. How are you going to build it, how are you going to make it. So the key aspects here, the key aspects are involves establishing the physical interfaces.

Then we also talk about the interfaces, these are interfaces are among operators and equipment, an example of this is like designing the driving location in a car, so in a typical car it will have a steering wheel, clutch, brake, accelerator at the three pedals, transmission lever, or a gear lever what we call it as, control stacks for light switch or indicators, wipers then air conditioner knobs, console and there is meters to specify the speed, RPM of the engine, fuel consumption, these kind of aspects.

So all that aspect, the physical interface of how the driver interact with the car that in the system is also one aspect of the physical design and then we also talk about the technical requirements as well or tech requirements. These are also key aspects of the system. So this

document is usually called as the physical design document and this physical design document consist of things like system configuration which involves interface descriptions.

How will they interfaces be, you know like if in the case of an automotive we decide how the, where that speedometer will be digital analog tachometer will it be inside which is the speedometer be larger than the tachometer all those kind of things. So the interface descriptions will be one.

Then the information display characteristics; how will the information be displayed. So if you look at the cockpit of an aircraft, you kind of know how the information is presented to the pilot in a particular sequential fashion because in a way, so that the pilot who are trained it is very easy for them to look for the information.

So wherever the location of the like for example the artificial horizon, they are typically located at a specific place where the pilot knows, he will look there, you will actually found the artificial horizon. The details of the engine are displayed in another CRT or the pilot to see and they are all usually positioned at the same place because they are already talking about a Boeing aircraft and an airbus aircraft that ideally almost around the same location, so that you can actually find okay.

This is where you look to find the details of the engine and stuff like that. So these characteristics are part of the physical document. Then other stuff is the user controls. How will the user control the system that is one thing, then operator skills and training levels. So how much you need to train the person, what type of stuff is to necessary, all these things are part of the system configuration document.

Then there is things like user characterization which is like for example, sometimes the special environment as we said as an example if one of the user is handicapped, then how will the interface be, also there will other constraints, another one was dealing with the left-handed, right-handed capability or ambidextrous capability of shooter when it comes to a rifle or an assault rifle, we talked about that earlier.

Then we also talked about this document, talk about physical limitations. The physical limitations involve first thing is the capacity, power, size, weight etc. So these aspects are the

physical attributes of the system, also too roughly to an extent gets specified as part of it. Then there is also technology limitations, this also gets part of the physical document or physical design document.

Here the technology limitations would involve stuff like range. If you take the example of the UAV range, precision, data, rates, frequency etc, all these aspects are part of this. Then it also involves necessary standards. What type of standard system should do and also it involves necessary equipments etc. So all these kind of equipments involves like whether is a specially built equipment or is an commercially off the shell equipment.

All those aspects are part of this physical document. So the third one basically talks about the how aspect of the system which basically the form, the physical form, the design form. So the first one, the operation another things we will talk about, if we take the example of UAV, will say UAV, UAV, UAV, but in the physical document there might be like okay here is the shape of a few sledge and something like this.

And here are the two wings of the UAV and here is where the propelleries or the propulsion happens. The tail is like a boom and then it has an inverted V-tail or something like this and the (()) (46:08) is here. So those kind of aspects, we will end of designing (()) (46:12). So what is the total length of the UAV, the total weight of the UAV, the material use, the size, the range all those aspects are part of this.

So that is a physical design document of the or the physical design document that we talk about it. So the physical design document should also be again as I said earlier synchronised or coordinated with the other two being operational and functional documents. So in the next class we will actually take an example and run through this and see how we will use unmanned aerial vehicle as a case on how systems engineering has been applied down to a development of an unmanned aerial vehicle indigenously.

Thank you for your patience listening. Good night.