Systems Engineering
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Lecture – 14.1
Requirement Analysis

Good afternoon, today we are on the systems engineering course 14th lecture and we are going to discuss today about requirement analysis and much more details and what are the different aspects of it. So far, we have been seeing systems engineering from the basic perspectives and today we will start looking into individual aspects of it. So today's presentation is requirement analysis as I said earlier and we will see what does this important step of systems engineering comprises of.

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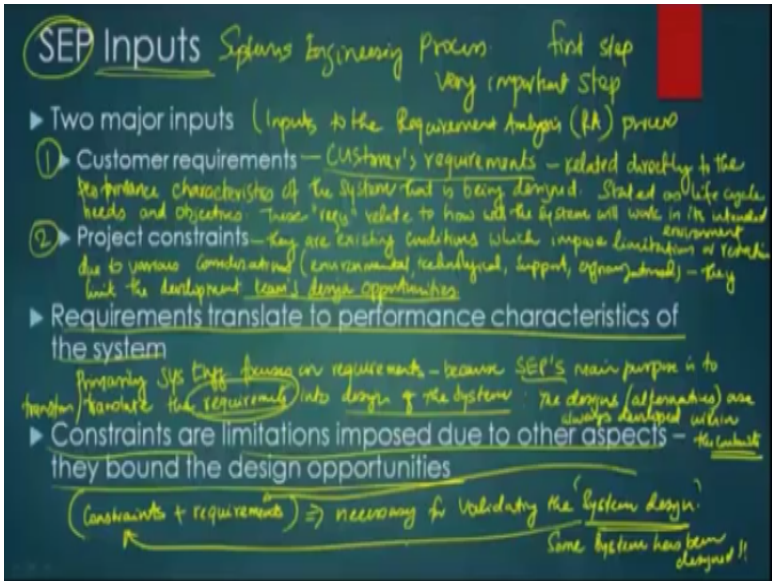

So to start with the, as we said SEP, this stands for systems engineering process. So requirement analysis is a very important step in the system engineering process as a very important step that is what we need to do, know or remember. Very important step and the first important step, it is also so the first step and you start this, you start from here. So it is actually in a way, that is why it is sometimes called as a SEP input, the input to the systems engineering process.

So it is first step in the systems engineering process and it is a very important step and it has two major inputs. So the inputs to the in a way to think about this, the inputs to the RA process to the requirement analysis process, we call this as RA, requirement analysis process

where comprises of first one is customer requirements and project constraints.

Most of the time, people call this as customer requirements, the right usage of it is customer's requirements. So what is it, customer's requirements is these are basically the requirement specified by the customer, which is related directly, this is related directly to what to the performance characteristics, whose performance characteristics of the system, of which system, system that is being designed.

So customer requirements are directly related to the performance characteristics of the system that is being designed at this point okay. Most of the time, these are stated as lifecycle needs and objectives. Many at times customer's requirement or customer's needs are usually stated as lifecycle needs and objectives and so in a way in the simplest layman language, the simplest way to think about it would be something like this.

These requirements, these means the requirements, they relate specifically relate on or relate to how well the system will work in its intended environment okay. So the question here is that these requirements, they relate to how well the system will work in the intended environment of the system where it is intended to operate or intended to function. So that is the first part, the customer's requirements.

Second part is a project constraints and this is also important because project constraints, they are existing conditions. What are they, they are existing conditions. What do they do, which impose limitations or restrictions due to various considerations and so there are many considerations, this considerations can be environmental, they can be technological, they can be a support, it can be organisational and so on.

So these are the conditions that impose limitations or restrictions due to various considerations that are outside the ambit of the system that is being designed, usually there outside the ambit of the system being designed. So what do they do, what is importance of this, the most important reason is they means the project constraints, they limit, they limit what, they limit the development teams design opportunities.

So the design opportunities, the team's capability to design a system that is being restricted or a constraint is being on it. So one aspect is the customer requirement, customer would need or

customer’s needs will be quite significant, quite good, well thought through an all those kind of things, but there are also constraints within which that needs has to be fulfilled.

So these two, the customer’s requirements or the customer’s needs and the project constraints are the two aspects that together comprise the input to the requirement analysis, RA process. So we also need to understand that the requirements this statement, requirement translate to perform a characteristics of the system. So the performance characteristics of a system is derived or obtained from the requirements, whose requirements, customer’s requirements.

So let us see how that can be talked about. Primarily systems engineer focuses on requirements. Usually people say systems engineer focus more primarily on requirements. Why do the systems engineer focus on the requirements, because system SEP, systems engineering, SEPs main purpose is to translate, you should translate what, translate the requirements into design of the system.

This is can be translate or you can also use the word transform. You are transforming the main purpose of systems engineering is to translate or transform the requirements into the systems design. So that is one of the reasons why systems engineer primarily focuses on the requirements, so one of the reasons why we focus also. Another aspect is the designs, remember we already said that instead of one design there are usually multiple designs or what we can call it as the alternatives.

The designs, they are always, the designs are always developed within, is always contained this limited within the constraints. So within the constraints, you develop the system, the designs to satisfy the requirements alright good. So as we said earlier constraints are limitations imposed due to other aspects or which bound the design opportunities.

So the thing is that the constraints plus what we call as the requirements together, they are necessary for validating the design, validating the system design. So the question here is you design to some system. So some system has been designed, this is accomplished. How do you check that this meets the customer requirements.

How do you check that this fulfils the constraints. So this process, the validation process is also an aspect of the systems engineering process. So that is why both the requirements and

constraints are important and that is one of the reasons why requirement analysis is also one of the primary most important step of systems engineering okay. So we now look into what are called as a type of requirements.

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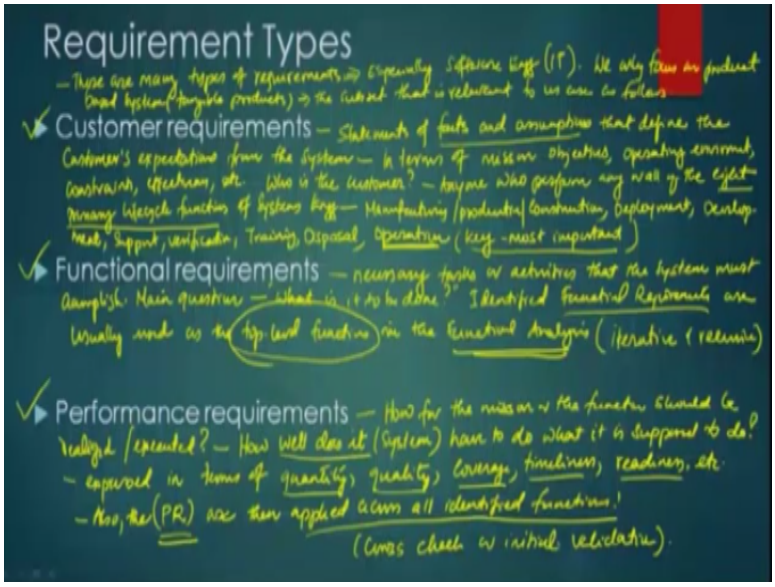

So one of the first and foremost thing is there are many types of requirements. Remember especially software engineering or IT, that growth in IT system have really created a complicated scenario, because of that there are lot of requirements that are been specified. People say these are the type of requirements. Some people call as customer requirement, functional requirements, performance requirements, design requirements, synthesis requirements, derived requirements so many of them.

But what we are going to talk here about is we only focus on product based system or what we call as tangible products and hence, the subset that is relevant, or is relevant to us are as follows. So we talk about the first and foremost requirement that is important to us is the customer requirement. We talk about this first one, customer requirement. So what is a customer requirement, what are customer requirement or what are customer's requirement.

These are in a simplest way, these are statements of facts and assumptions. So what does this statements of facts and assumptions do. These statements of facts and assumptions, they define the expectations, the customer's expectations from the system. So in a way, we are defining this facts and assumptions, they define the customer expectation. What does a customer expects from the system, that is being part of the customer requirement system.

And how are these things stated, they are usually stated in terms of or with respect to machine objectives, the operating environment, then we also have constraints and then effectiveness etc. So the customer will state facts and assumptions based on what he or she is expecting from the system and these statements could be in the term of machine objectives like as we said in the UAV example that the UAV should be able to carry out surveillance and reconnaissance missions.

It should have an endurance of six hours or more or something like that. We discussed those kinds of things. So it might be expressed in terms of objectives of the mission. It could also be expressed in term of it should be operating in all weathers, it is like an operating environment, it should take off from a simple, you know hard surface whether paved or unpaved. There should not be any need for a proper runway.

So that is another operating environment requirements, you can say it should be silent and the propulsion should be based on easily available type of fuels and those kind of stuff. So thus are constraints and it should be effective to be operated within for low intensity conflicts, so that becomes the effectiveness of the system etc. So there are many ways that the customer will state the requirements.

So obviously, the fundamental question is who is the customer, so let us ask this question, who is the customer, can we define that person, can we pinpoint who the customer is. The answer to this problem is anyone, who perform any or all of the eight primary functions, you can call it as lifecycle functions of systems engineering, that person is called as a customer.

Anyone who performs any a single or a subset or a whole of the eight primary lifecycle functions. We already discussed, what are this eight primary lifecycle functions, but if you do not remember let's discuss them once again, what are those eight primary lifecycle functions. One will be the manufacturing or we can talk about it as a production or the construction, this will all be one lifecycle function.

The other will be deployment. Third one will be development. I am not writing this in any particular order, but development, and there is a support, then there is a verification, then there is straining, disposal and obviously as operation. I write operation as the last one because this is also the most key, this is the key or the most important. So in a way this is the

key customer. The operation, the guy who operates the system is a key customer.

But the person who is involved in manufacturing, production and construction of the system or the deployment of the system or the development of the system or the support of the system or verification, verifying that the system has been developed in fact is what it is meets the customer requirements and the constraints. The person's or the organisation that are involved in training, involved in disposal, they are all customers, they are all are part of the customer's.

Obviously yes, the importance is always given to the guy or the customer who is operating the system because that is a key customer, but other customer's are also important. So requirement specified by all of them becomes part of the customer requirements okay. So I hope that it makes the customer requirement aspect clear. So then the second aspect there we need to talk about is the functional requirements.

So the functional requirements, what are they, if you want to talk about it or if you want to make clarity on this or if you want to define this how do you do that. So loosely stated, it can be stated as the necessary, what are functional requirements, the necessary tasks or activities that the system must accomplish. So the necessary task or activities that should be accomplished, who should accomplish, the system should accomplish.

So like for example, when we talk about the UAV, what are some other functional requirements. The functional requirements would be it should fly obviously, it should carry a surveillance or reconnaissance payload. You should be able to stay for a long time in the air, it should be autonomous. It should decide when to fly, where to fly, what direction to take, when to turn, how much to turn, all those kind of things you should be able to do.

So those are the aspects, it should be able to perform all those necessary task or activities to fulfil the surveillance or reconnaissance requirements of the system. So adding to this okay, so the main question here, main question that need to be answered here is what is it to be done. This is the question that need to be answered, what is it to be done here and also the identified functional requirements are usually used as the top level functions in the functional analysis.

This is another aspect of systems engineering functional analysis, we will get to this little later down the course as we progress, but when you identify the functional requirements initially, we are not talking about the detail, we are talking about functional requirements identification during requirement analysis. When you identify these functional requirements, then they typically form the top level functions for the function analysis.

Remember, we talked about this as an iterative and recursive process. So the top level from where you start before you drill it down, those aspects, those function basic statements are top level functions are derived out of the functional requirements out of here okay. Then comes we talk about the third aspect which is the performance requirements. So the fundamental question here, here it is easy to start with the question.

The question is how far the mission or the function should be realised or executed. The question fundamentally here is how far the mission or the function should be executed or realised or executed or putting it in a much simpler form. You can ask this question in a different way, how well does it, does it means, does the system, it is the system okay. How well does it have to do what it is supposed to do.

So if somebody says, in the UAV, do surveillance, to what level, obviously, yes if you want to identify the surveillance as okay, there is an automobile, a car is going on or an SUV is going on, a sports utility vehicle is going on, or a truck is going on or a bus is going on, is that identification sufficient enough or do you really want to identify the number plate of the car or the make and model of the car or do you want to identify how many people are travelling in that vehicle.

So if you just want to see okay, there is a vehicle that is travelling than that is one type of requirement, that is one way of, one level of how well you are doing the surveillance. If you say, I can see the colour, I can also see the number plate of the car or the license plate of the car then that is a different level of functional requirements or performance requirements.

You can identify, I can also see the license plate and as well as identify how many people who are travelling in that car. Then that is a different set of functional performance requirement. So that is where how well does it, the system how to do what is supposed to do. This is a qualification, how well it has to be done. To further elaborate on this it is usually

expressed in terms of quantity, quality, coverage, timeliness, readiness etc.

So performance requirements again as I said these are from the customer side, we are talking about the input to the systems engineering process. So there are multiple way these gets stated and the performance requirements many at times stated in the terms of quantity, quality, coverage, timeliness, readiness etc these kind of stuff. So an example of this would be the UAV should be ready to be launched, assembled and ready to be launched in 20 minutes that is a readiness requirement.

It's a performance requirements that mean all the joints, connections all those things, the interconnecting cables everything should be done. The system should be ready, ground checked, ready to take off in 20 minutes means the designer now how to design systems, which will actually meet this 20 minutes requirements, the performance requirements for assembly and take off readiness, provided by the customer.

We will discuss a much in much detail the UAV as a specific case immediately after this completion of this lecture, so that we can actually see how we run through the development of that system but anyway elaborating on this also the performance requirements, I call it as PR, the performance requirements are then applied across all identified functions. So once you identify a performance requirement and you establish a performance requirement, it is then applied across all identified functions.

So if you say that okay the endurance of the aircraft is, it is supposed to stay in the air for eight hours, so then that requirement gets translated to different aspects of the function that are identified, you know, what needs to be done, is that eight hours going to hamper the surveillance requirements.

If the camera that is put on the system is not capable of doing a recording for eight hours, then yes, that will actually hamper the functional requirements of the system. So that is one of the reasons why all the performance requirements gets cross, so this is actually a cross check or initial validation that happens here. So we seen three type of requirements, customer requirements, functional requirements and performance requirements.

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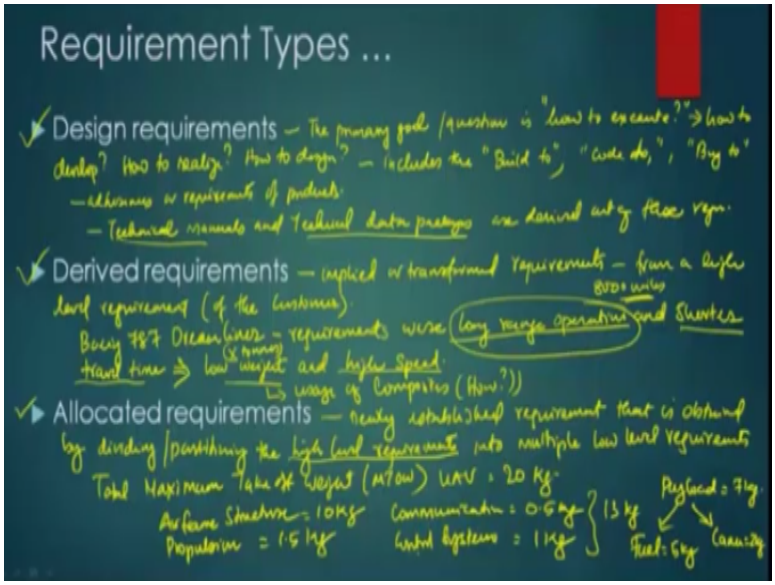

So now we will see other three types also which we have continued, which is called as a design requirements, derived requirements and allocated requirements. As I said earlier, there are many more, but these are the most important things that are applicable to our work. So let's talk about the design requirements first.

So what is a requirement, design requirement, the primary goal or primary question is how to execute or this is where the person, who is building the system asking the question, how to build or how to execute or how to develop the system. So this some people will also call it as how to develop. Some people call it as how to realise, how to design. All these questions are different manifestations of the design requirements of related to the requirements analysis.

So this also includes the build to or code to and buy to okay. In a way these are the adherences or requirements of products. So you can say this product is build to a specific standard, design standard. You followed all the connections, interconnecting cables are using some one particular type of IEEE, some connectors or something is being used, which is where we are saying you are adhering to a standard. You are basically doing according to a standard.

And this is where you are imposing a design standard, for realising some specific aspects because the reason of using this connector is it will reduce the assembling time, something like that. So in a way, the outputs like technical, manuals and technical data packages are derived out of these requirements. So when we say that we are working on the design requirements, the output out of that to a large extent translates to the technical manuals and as

well as a technical data packages of the system.

So design requirement is another aspect of the requirement analysis. Then comes is the derived requirements, these are as the name says, these are quite easy to understand, these are implied or transformed requirements. Where are they informed or transformed, they are from a high level requirement of whom, of the customer. So the customer might have specified a high level requirement and from there something has been implied or transformed to realise there customer requirement.

So what are the stuff that is implied or transformed. So let us take an example, we discuss the case of dream liner Boeing 787. So if you think about the dream liner one of the things that we stated was that, the requirements stated by the customer, requirements where long range operations and shorter travel time. So the dream liner or the Boeing ended up creating the requirements as long range operations and shorter travel time.

So this is a high level requirement. Derivation out of that could be translated to something like low weight and high speed. This could be further broken down, low weight could be talked about of usage of composites another things. But that is not part of this at this point. This is about how okay, how do we accomplish, that is not part of the requirement analysis at this point. It will become a part much later down the road. We are talking about the initial stages.

Initially, when we are talking about a derived requirements, you are translating a high level customer requirement into a implied or a transformed requirement, which can be further translated into something that is a quickly or technological achievement or some as specification of a subsystem that would actually help you to realise that transformed or derived requirement.

Then is the last one which is called as the allocated requirements. So here this is a little bit tricky one, but let us see how does this works about. So by definition this is actually it's a newly established requirement that is obtained by, how it is obtained, that is obtained by dividing or partitioning the high level requirements into multiple low level requirements.

These are different from the derived requirements because you are kind of not translating or

transforming it into something else and somebody says long range operations it does not gets transformed into as low weight. Here, for example, let us say, if you say the total maximum takeoff weight which is usually called as MT or W of the UAV.

Let us say, we call that as 20 kg, then this 20 kg can be divided into airframe structure, let us say 10 kg, talk about it as propulsion, say 1.5 kg, then we can talk about it as communication 0.5 kg, control systems, let us talk about it as a 1 kg. So we have 10, 11, 12, 12.5 about 13 kg of this and we then talk about payload equal to 7 kg fulfilling the 20 kg, a total requirements.

So the 20 kg gets subdivided into different components of the UAV, and then you can further talk about the payload being further divided into fuel let's say 5 kg and camera equals 2 kg, I am just using numbers. So here the same high level requirement is being subdivided into its component requirements, it is allocated about different aspects of the system. So this is the difference between allocated requirements and derived requirements because derived requirements where talk about long range operations.

So let's Boeing said 8000 miles nonstop flying range might have translated to a weight or something called as like some extern, so something like this, so that they can actually realise this much of a range. So here it is translated or transformed into something. Here it is actually subdivided into the same aspect. So that is what an allocated requirement all about.

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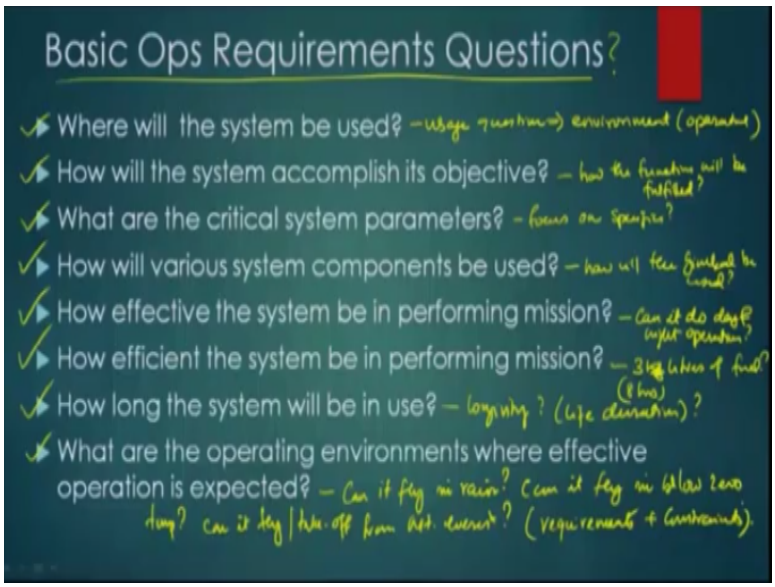

Well continuing on this, when you do the basic operational requirements or when you do the operation requirement analysis, you end up asking a lot of question, ton of questions. So the

first question that we need to ask is where will the system be used or this is the usage question or which will give the environment or the operational environment aspects of the system.

So we can properly answer this question, where will the system be used, it will actually give you the operational environment, once you answer this properly you will be able to define where all will be the system be used in its operational capabilities. How will the system accomplish its objectives which is a second question. So this is the what you call as it's a how the functions will be fulfilled or in a way how will the system operate, that is the question that you are actually underlying question behind this, this aspect.

So once you answer this question properly, you will be able to identify how the system will be operating to achieve its objectives. Then we talk about what are the critical system parameters. So if you are to focus on something, or focus on specifics, what are things that you need to focus on, what are the critical things that need to be there to ensure that the system works properly.

Like for example, one of the critical parameters for a UAV will be what is a stall speed, so and what should be the altitude. So the system will always check for whether the current in air speed of the system is more than the stalls speed so that the UAV is flying because if it is less than the stall speed then the UAV is not flying it is falling down.

Similarly, it is also be talking about at what altitude it is flying because as you go on hire what happens is the air becomes thinner, air becomes thinner it reduces the left, when it reduces the left, then you require to need to fly faster to derive that same amount of lift. So it might be outside the performance realm of the engine.

So you might not want to fly above as a certain altitude which will be the operational sealing capabilities of the engine. So these are the critical system parameters that one need to identify and understand when you are designing the system and then the next question will be how will various system components be used, so in the case of a UAV, we will talk about how will the gimbal be used to control or guide the camera. How will the battery changing mechanism will be used.

How will the communication system be used, where will you have the redundancy in communication, whether the payload and telemetry will be on two channels or one channel or they will be merged to separated, split and encoded all these aspects, how will the various components of the system will be used and functioning that aspect comes out of this particular question and how effective the system will be in performing the machine.

So like for example, you can say that everybody want the system to do everything in the world under the sun, but not possible. So in the case of UAV, one question that you can ask is can it do day and night operations, can it fly in the day and can it fly in the night, day you might require just a normal camera because you have sunlight to see the things and you can take the video or picture of it.

But in the night it might not be the same, you might require an another thermal imaging camera to see images in the night to differentiate temperature and aspect. So it might not be possible to carry both of the payload at the same time. So then, if the time changes from day to night, if you are only carrying one payload then you have to land the UAV, change the payload and then take off again

But if both the cameras are mounted at the same time, then whether the time changes from day to night it does not matters, the system can actually continue to fly. So that is also another aspect. How effective the system will be in performing the machine. Then the question would be how efficient the system will be in performing the machine.

So let us say if you say we put 3 litres of fuel in the UAV, how can it fly for eight hours, then you can say based on the input versus output you can find that okay this UAV is operating at x percent efficiency, how efficiently it can actually utilise the fuel, the fuel efficiency is one aspect. You can also talk about you know how much of fatigue is developed by the pilot while operating the UAV. So the UAV does not create pilot fatigue, then it’s efficient in managing pilot fatigueness.

So the fatigueness is about the how well it can do things, where as the efficiency is about how it the system can perform or derive, deliver better output or more output for the same level of input. Then, next question is how long the system will be in use, or the longevity or what we call as the life duration. Then, at what phase we will be using, how long we will be using, and

when you will be talking about disposing the system, that aspects.

Then last thing question, what are the operating environments where effective operation is expected. So we talk about UAV, can it fly in rain, can it fly in below zero temp, can it fly or take off from Mount Everest. So these kind of questions, so like what are the operating environments, you are defining where the system is expected to be put into use and it is very important for any person who is designing because this is a part of the requirements and it is also a part of the constraints as we talked earlier.

So these kind of basic questions that we talked about help you to realise what are the basic operational requirements of the system because once you understand the operation requirements, then you can translate those things into performance requirements. Remember, for operation requirements are different from the performance requirements. So now we talk about the aspects of good requirements.

So anybody can make a requirement as this as specific requirement but when do you call that requirement okay, this requirements specifications is actually good. This is bad, this is not up to the mark. It needs to be revised. So what are some of the characteristics by which we can classify the goodness of a requirements.

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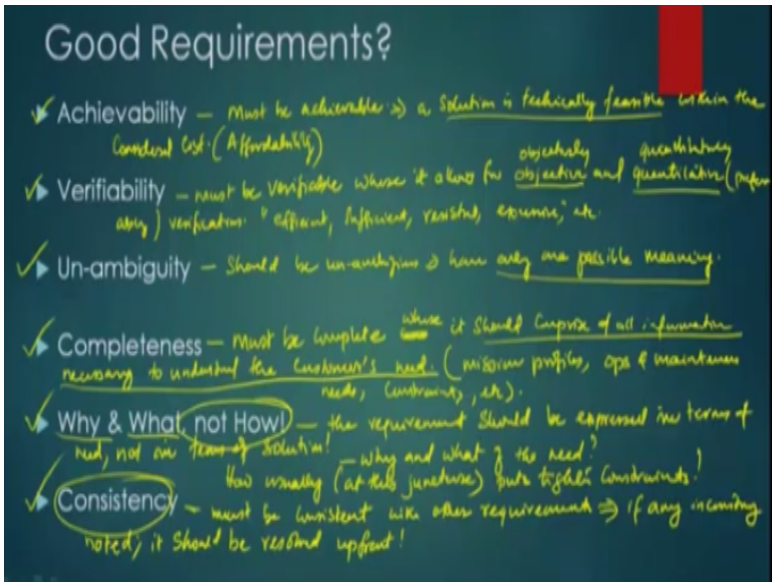

So the first one is what we call as achievability. This means any requirement; a good requirement must be achievable which means a solution is technically feasible within the considered cost. Within the cost that is considered, within the affordability, this cost is

equivalent to the affordability. Within the affordability of the system that is being already talked about or discussed with.

There is a technically feasible solution available or in a way if that is there then that requirement is achievable, a specific requirement is achievable. So if somebody comes and says the UAV should take off with a speed much more faster than a rocket that is going to the moon, it might not be something that is technically feasible so then that will not be good requirement. So somebody would say it should be able to climb 100 feet and like one minute achievable.

So these kind of, so a requirement which will allow the customer to fulfil what he or she is looking for and is technically feasible within the appropriateness of the cost is what we call as an achievable requirement. So achievability is one of the prime importance of a good requirement. The second aspect is what we call as a verifiability. So it must be verifiable where, so what is verifiable, where it allows for objective and quantitative, this quantitativeness you can think about as preference, preferably quantitative verification.

So if you say that if you talk about a requirement, you should be able to objectively and quantitatively verify this or obviously you will ask a question, can it be qualitatively verified, yes you can but the things like if you talk about the qualitative stuff like it should be efficient, sufficient, it should be resistant, it should be excessive, these kind of words does not allow for a verifiable stuff. If I say that the watch should be water resistant.

So if I buy a watch and say it should be water resistant, what does it mean, I mean, it should be water resistant like you just put it in a bucket of water and should be resisting or you take the watch to 40 feet below the sea and you should still be, the water should not enter the system. So many a times people will specify the water resistance as a depth, take a watch and look at the bottom of it, it actually specifies how much is the water resistance.

So that is what the verifiability of it. So the way to verify that it is taking the watch, take it to that particular level of depth in a water body and see whether the water is entering the system or not. So that is a verifiable requirement. Not just saying that it should be water resistant, that is not a verifiable requirement because water resistant can be a whole spectrum of things. So that is a verifiability aspect of a requirement.

Then the third one we talk about is un-ambiguity, un-ambiguity means it should be un-ambiguous or have only one positive meaning. So it should be un-ambiguous. So if the person, if you look at the requirement and get two or three different interpretations of the requirements then that is ambiguous. So it should un-ambiguous, there should be no ambiguity or there should only one possible interpretation or one possible meaning to the requirement.

If that is the case, then that requirement is considered as a good requirement. Then the next one we talk about here is the completeness of the requirement. So it must be complete. So obviously you can say it must be complete but what does this complete means, complete and complete where it should comprise of all information necessary to understand the customer's need. So it should be complete all aspects of the customer's need should be covered in the requirement. That is why it makes a good requirement.

So what are the some of the customer requirements, those will be like machine, profiles, operations, ops, and maintenance needs, we talk about the constraints etc. So the customer might have many needs, customer needs might be quite a lot, but when a need becomes or the requirement becomes a good requirement when it is complete. When it is comprise of all information necessary to understand the customer need. That is when you call it as a complete requirement.

Then comes the next part which is called as why and what, not how. So what we talk about it is here the requirement should be expressed in terms of need not in terms of solution. So it is like somebody making a statement that okay, I am thirsty I need water, or I am thirsty. So the person can provide you water or tea or juice something like that.

So if I make the statement saying that I am thirsty so please take a glass of water, wash it in warm water, then fill it with a water that is at a temperature of 40 degree Celsius and put Vitamin tablet into that or something like that. So I am just giving a really ridiculous example to say what not to do. So the how is not, the important part. The customer should not specify the how. Customer should only specify why and what okay.

So in a way, we are talking about why and what of the need. So who gets to do the how, the

designer, how is the need going to be fulfilled, that is as part of the design of the system. So let that be not part of the requirement, it is usually sometimes people try to get into the how, the customer tries to get into the how which usually puts a much larger constraints.

So the how usually, how at this juncture or at this time of the system development usually puts tighter constraints. So the designed might not get that much of freedom to really realise the system to the fullest potential. So this is also an important aspect of the system or good requirement. Then we talk about is the consistency, well, this is a very common, very obvious one but the important aspect distinguishes here is, it must be consistent, consistent with what, with other requirements.

So if somebody says I want an aircraft which is light weight and say please built it with stone then obviously it might not be possible. So the consistency or what you call as the user should know where it becomes, where the requirements are consistent and where the requirements are not consistent. So like, for example, if you find if any inconsistency noted it should be resolved upfront. So many a times, this is one aspect where the user needs gets confusing and consistency aspect and quite a lot of the user requirements can be inconsistent.

If so, then they need to be resolved at that point and that the user need to or the customer need to decide, which one or which way the inconsistency will be resolved, is it -- because you will have to pick and choose or favour of some certain performance characteristics or requirement. So that discussion usually happens with the customer or the user and once that it is done, then the inconsistencies are removed and then that the need becomes a consistent.

So if the requirement is an achievable requirement, a verifiable requirement, un-ambiguous requirement, it is complete in itself and it is focussing on why and what and not on the how and is consistent with other things, then we call that as a good requirement at this juncture. Thank you.