Systems Engineering
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Lecture - 10
System Environments

Good Morning. We have come to tenth lecture of System Engineering today. Title System Environments. So, we will be discussing about the environment with which the system operates and I am Prof Philip from IIT, Kanpur. So, we have been studying quite a lot about system engineering and we slowly started understanding the system the hierarchy of the system and now today we will discuss about the environment related to the system.

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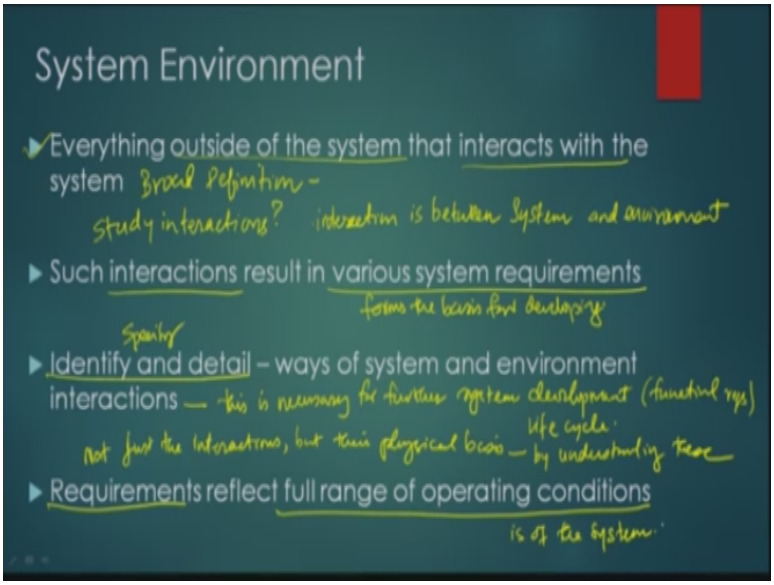

And it is important to know this because today we will also come across the first tool of systems engineering called context diagrams and also we will see why these tools of understanding the environment of the system engineering of the system is important. So, in the simplistic sense if you look at it system environment is everything outside of the system that interact with the system.

So, it is a very broad definition so you can think about as a broad definition in which everything outside of the system that interacts with the system. So, when you say everything outside means it has nothing to do with the part that is within the system and we will see how this classification

happens later and they also interact with the system. It is not that they are just staying there it is also causing some interactions with the systems and why do we need to study the interactions.

Why are these interactions so important? The interaction between the system and the environment, the interaction is between system and environment. The interaction gives you such interactions when you study these interactions it do result in the developing the various system requirements or it forms the bases for developing. System engineer when he studies this interaction it forms the bases for developing the system requirements and it is also important.

It should also be understood that it is important to identify, specify in detail. So we will add here. Identify, specify and detail. The ways in which the system and environment interacts. Why? Because, this is necessary for further system development. So, it is also necessary for the system life cycle and all those kind of things and it also creates what we said earlier is it also comes up with the various, the development includes the functional requirements.

What the system should do? And we should also understand that it is not just the interactions but their physical bases. So this also need to understood. Why? Because by understanding these requirements will end up reflecting the full range of operating conditions of the system. So, the operating conditions are of the system. So, understanding the interactions and their physical bases both of them help us to understand the requirements that reflect the full range of operating conditions of the system.

So, it is important that we study the system environment and everything outside of the system that interacts with the system is what we call as a system environment.

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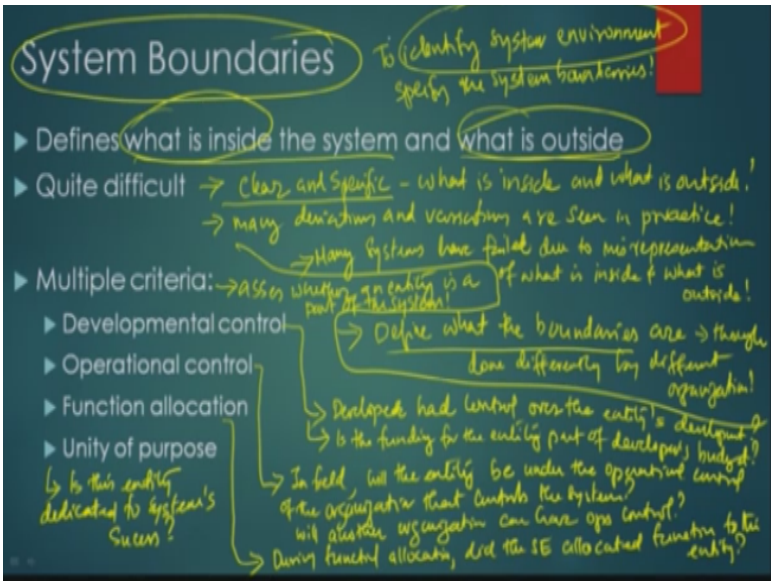

So, we move to the next one which we talk about in the system boundaries. It is a very simplistic definition but the important part is to identify system environment. If you need to find out what is the environment with the system is operating specify the system boundaries. It sounds quite simple. It simply says what is inside the system and what is outside. It is a simple definition. It is quite difficult. There are two, three difficulties.

One is that it needs to be clear and specific what is inside and what is outside. So, this is one part of the aspect. So system boundaries are even though it sounds very simple. It is quite difficult to clearly and specifically mention what is inside and what is outside and it is quite difficult in practice. Many deviations and variations are seen in practice.

That about the second part and the other aspect also is that many systems have failed due to miscalculation of misrepresentation of what is inside and what is outside. So, then these aspects have already been mentioned so then the important task is to define what the boundaries are? So, we are here to define what the boundaries are though done differently by different organizations. This boundary definition defining the boundaries is usually done quite differently from organization to organization.

So depending upon where you are and what you are dealing with you will probably find different ways of doing it but at the end of the day all it amounts to it is defining clearly and specifically

defining what is inside and what is outside. So, there are few criteria that will actually help us in making this decision. So the criteria is to assess whether an entity we already seen what an entity is. Entity is a part of the system.

This is what we are trying to do. The criteria is assess whether it is part of system or not. So, the first criteria is what we call as development control. The development control, the first question we ask is the developer did the developer had control over the entities development. So, first question did the developer the person who developed the system had control over the entities development and another question that usually ask is, is the finding for entity part of developers budget.

So, did somebody pay for developing things? So most probably then it will be part of the system. So it would be a part that would be inside that is associated with the system. That is one way to look at it and if the answer to this is no. One of these questions are no, there are many different questions asked by different organizations. So, I am just giving some few examples of what types of question are? Another aspect you can think about it is operational control. So, here the question in field, will the entity be under the operational control of the organization that control the system. If you ask this question, then it is quite possible that okay that if the entity is also controlled by the same organization that controls the system most probably it is part of this.

Another question is will another organization can have ops control is this also possible? So this question also becomes part of assessing the operational control. Then another aspect of what we talk about it is the functional allocation. The third aspect we can think about it the functional location is the question usually is that during functional allocation did the system engineer allocated functions to this entity.

So, did the system engineer allocated the functions to this entity at the time of functional allocation studies. If the answer is yes, probably the system will be part or this entity will be part of the system. And finally what we call as the unity of purpose which is this entity dedicated to systems success. This is another question and it is very common that lot of the industries and organizations who were in the system development will have multitude of question.

These are some few representative questions that you can create to clearly delineate whether the entity is within the system or outside of system. The important part is that if you cannot clearly define the boundary. If the system boundaries are not clearly defined, then it is very hard to identify the system environment. So those are the two aspects that we need to keep in mind. So this exercises of understanding what is inside the system and what is outside the system though appears to be trivial is quite difficult.

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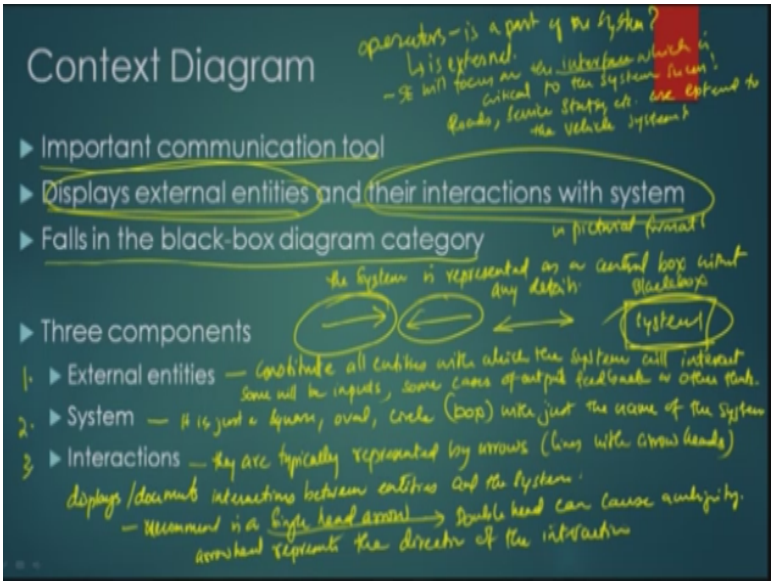

And also what happens is some of the other aspect is before we get into this context diagram we also need to think about few things the first aspect that we talked about this is what you call as the operators. They are an important part of the system usually the question comes is whether the operator is a part of the system. This is a question usually and the answer to that always is that operator is external.

Though, there are organizations who consider them as internal but most of the time the operators are considered as external to the system and the reason for that it is there is no way you can control the operator as such and you think that there are multiple type of people will operate the system and everybody will have their own styles and aspects, so the way, they operate the system will be different hence the system engineer will focus on - the SE will focus on, what he will focus on?

The interface which is critical to the system success so the important aspect the system engineering aspect is the interface where the operator and the system interacts, the interface of the operator and the system. is what is the system engineer will focus on. Rather than focusing on the type of operator because operator can change. Similarly, the other aspect is sometimes the operating environment like roads, service stations, etcetera are external to the vehicle system.

Sometimes people do argue that well you look at the road then you design the vehicle or design the suspension. So, it is part of the system. Not really true. I am using this an example. Because the vehicle usually will get designed for operation on different types of roads like concreate road, well paved road, roads with pot holes, rough terrain. It could be off road multiple of ways. So you do not really design the suspension for just one particular country you actually try to develop it for multiple or different types of surfaces.

You cannot expect the same surface of road to exist all over place. So considering roads or otherwise people will talk about okay the service stations. The availability of the service stations is also another aspect of vehicle design or the system of vehicle how we design it not necessarily true. The presence and absence of a service station in your locality is not a factor of how you design the system or how you design the vehicle.

So, those are also things that are external to the system. So, there are some of the common example where I have seen people making this mistakes but I thought I will point it out before we get into this. Okay. So now we talk about the context diagram. This is the first tool that we actually learned as part of the system engineering and what context diagram? It is an important communication tool. So first and for most it is a communication tool.

Communication tool between the users, the system engineers the designers and everybody to understand what is a system and what is the entities and how the interactions, the boundaries, and as well as the system environment. So, context diagram is an important communication tool that is the most important part of it and what does it do is? It effectively displaces the external entities and their interaction with the system.

So, the external entities and the interaction with the system are displayed how? They are displayed in pictorial formate. You can see that a lot of the tools that are used by system engineers are in pictorial formate because a picture is worth thousand words. So, it actually helps in a understanding the system and the boundaries. It also falls into this particular category called the black box diagram.

It is called a black box diagram because the system is represented as a central box without any details. So, you kind of draw a box and say system in it. So, this is like you do not know what the system is doing that some system is there. So the entire thing is unknown to you, you do not know what is going on inside the specific details are not available hence this appears to be like a black box to you.

So such diagrams where the details are not available are actually are called as the black box diagrams. So the context diagram actually also fall into this criteria and there are three major component of the context diagram and the three components are number one is the external entities, number two is the system, and number three is the interactions and you will what each of them are.

So, the external entities they constitute all entities with which the system will interact. So what we are doing here is that the we are defining the all entities with which the system will interact. So in another way to think about it is some will be inputs or some will be providing inputs. Some cases it will be outputs. So the system output might be used for it and some cases it will be also things like feedback and or other threads stuff like this is also part of it.

So, we will see this in detail but some of them may provide input some of them will provide output and someone of them will probably be proving feedback another aspect of systems. But they interact with the system in one way or the other. Then we talk about what is the system? It is already been defined system, system, system many times but in the context diagram it is just a square, oval, circle, let me called it as a box, it is not just a box it is a square box or an oval or an circle with just the name of the system.

There are variations of context diagram where people are specified the details of the system but not necessarily the typical classical context diagram expect just you to draw a box or oval or a circle and put the name of the system there and that just represent the system. Because understand that the focus of this context diagram is to display the external entities and their interaction with the system. It is not a tool to the diagram the system.

It is a tool to diagram the environment of the system the entities of the system and the interaction of them with the system. So the system is just kind of say here is a system then what are the other nitty gritty details of it you are not worried about. And then he talks about interactions the third components of the interactions. So, they typically represented by arrows or lines with arrow heads.

And there are multiple conventions used here again some people use these kind of arrows some people use double side of the arrows stuff like this. So, the trick here is that what do these arrow do? They displace our documents into actions between entities and the system. So these arrow represents the interactions between them you should recommended is the single head arrow. Usually people prefer to use this or this because the double head arrow.

Why are you using single head arrow? Double head can cause ambiguity because I earlier said that it is a difficult process and if there is any confusion in this regard when you classify a material or an entity which is actually an external entity as an internal entity then the behavior of the system will be significantly affected. And there are many instances where it has resulted in the failure of the system.

So the arrow head represents the direction of the interaction. So whether it is going to the system or going into the system out of the system all those kind of aspects is being displayed by the direction of the arrow head. And as I said earlier it is usually prefer to use a single head arrow to minimize ambiguity in this case. So let us see how does it looks like realistically.

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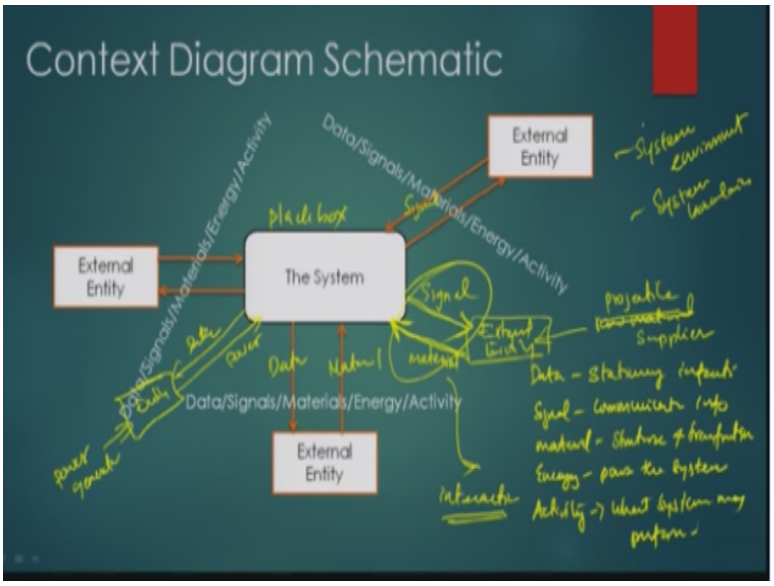

So, the first box the black box what we talked about this is the black box that I was talking about. It is just a box in which the name of the system is put in and then you have different entities I just put external entities like this. But you can put the name of the external entity which are the one that are interacting with the system and then we have different arrow heads. Single arrow heads is showing the directions of what is coming into the system.

And what is going out of the system and these entities are typically data, signals, materials, energy and activity. So, we have already mentioned that what is these aspects the data, signal, materials and energy and activity because earlier we have seen these as the entities of the system in the previous example. The data is as we said earlier, data was the stationary information. Signal we know that is the communication info.

We show material as the one that provides the structure and transformation. Energy, power the system and activity that is what the system may perform. So, all these are part of the interactions so you can kind of think about I will show an example you can create something like a situation like here. You can say this as external entity and you might have something like this as signal and you can say as material.

So, in an example this could be an external entity could be somebody like a row material supplier or instead of raw material let us call it as a projectile supplier. So, let us say this is a field laury

gun, a signal goes to the guy who applies the projectile say is it okay? We are running out of projectile. So supply and then the material the rounds of that laury rounds actually gets applied back to that.

Similarly, you could have a situation where you can actually have a data coming in and you have an entity and the power going inside. So something like this could be a power generator or something like this. So, somebody says okay fine we require more power or more electricity run out. So then the next channel generator actually supplies the power to the system this typically happens in the UAV system and all. So, if you think about it.

So, by doing this diagram it becomes a very simplistic mechanism and arrow head we can write what you are doing. Whether it is materials, whether it is energy, whether it is data, whether it is signal all those kind of things when you write on to the arrow head and the arrow head shows the direction so that means here the signal has gone from the system to the external entities and the material has gone from the external entity to the system.

So, it tells you the flow. The interactions so this is what we call as the interaction in a diagrammatic fashion. So, I hope you guys understand the context diagram which is a simple graphical tool to understand the system and the externalities in interaction. So, in a way what we are doing here is that we are talking about the system environment, system boundaries both are covered as part of the context diagram.

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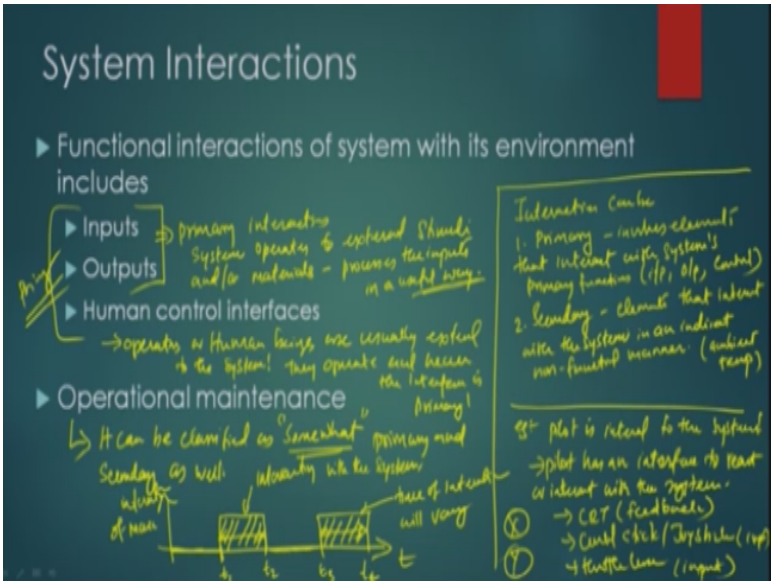

So, we talked about the system interactions and system interactions as I said earlier it is we basically grill it down to the entities as data, signals, materials, energy and activities. So we can think about in another way to think about it is that the I will kind of use some part of this slide for explaining the background behind it. The interactions can be defined; number one it can be primary interaction. So, what is the primary interaction?

It involves elements that interact with systems primary functions. The primary functions include input, the output and control. So mostly all elements that interact with this system primary function are what we call as the primary interactions and then there is something called as a secondary interaction which involves elements all elements that interact with the system. Interaction is always with the system in an indirect, nonfunctional manner.

So, here an example of this is the ambient temperature. So you have a heating and a cooling system then the ambient temperature outside is one factor that determines the system how much of cooling is required and what level of cooling is required? How much of energy is need to generate that much of cooling or lower the temperature of the room to a one particular level is an example of that. So the ambient temperature outside is an example of secondary interactions.

So, now we will talk about what is the input and outputs. So the inputs and outputs as I said earlier this is part of the primary interactions and what do they do? Typically, the system operates

to external stimuli. Stimuli is can be data, it can be feedback or whatever it is. It opens to external stimuli and our materials can be stimuli or materials and what does it do? It processes this the inputs in a useful way to prove some reasonable output.

So, the inputs are provided by the system by sending the external stimuli and or getting the feedback on materials and stuff like that and then it process. So, in a manufacturing system the external stimuli are the material. The material arrives then yes you modify them and then produce a part which becomes an output. And then the output is based on the input that actually comes in and the important part is it is in a useful way.

As I mentioned earlier, operators or human beings are usually external to the system. An example like a common confusing example I will just use this part an example of this is people say pilot is internal to system. I have seen people doing this classification. Well, not necessarily here because a pilot has an interface to react or interact with the system that is we using the CRTs then the control stick or the joy stick throttle lever etcetera.

CRT will provide him the feedback or how the system is preforming which has various signals. Joy stick is where the input comes into picture. Throttle is also an input and the behavior of an aircraft the flying, it is gaining altitude, losing altitude, turning (()) (33:07) all those kind of thing as pitching. All this part of the behavior system is doing something useful based on the inputs of the pilot.

So, if you take the pilot x or take pilot y it does not matters as long as they are trained they are capable of operating the system. So, you do not design a aircraft for a specific pilot you design it for a person any person who has the sufficient training to operate the system. So, in a way a pilot is even though a person sits inside the system and operates it the person is external to the system. So, the human control interface as I mentioned earlier is of significant importance.

Because the operators of the human being are usually external to the system and these are the people who actually they operate and hence the interface is primary. So, if the pilot interface is not very good then the behavior of the aircraft or it will be quite hard to control the aircraft.

Some people do make fun about certain interface designed by in earlier days because people sometimes say you design an aircraft and then you put a pilot into it and you hope that the pilot figures it out kind of a thing.

So then of late then ergonomics and anthropometry and all other aspects control system design etcetera came into picture and then the cockpit was redesigned for better control of the aircraft and less fatigue making the operation more efficient stuff like that. That is all part of the system engineering. So, the human control interface is also a primary aspect of the system because as I mentioned earlier input, output and control are the three aspects.

All these three are primary. Now we talk about the operational maintenance. This is kind of tricky because some people classify this as primary. Some people classify this as secondary. It can be classified as somewhat I use this word in a sense somewhat primary and secondary as well. Why? Because the after certain point of time after the system has been operating for some time it reaches a point where the maintenance has to be performed without which the system cannot proceed forward.

So, at that point it becomes a very necessary, important function that need to be it would interact with the system directly. And it would influence the primary function of the system at that point. But once you have done with the maintenance then until the next maintenance the maintenance infrastructure is not interacting with the system. So, it is like if you think about it in a time scale the time t.

And if you map the interactions of maintenance it will be if you start this as a time t equal to zero it will continue like this and at a particular point when the particular t reaches t 1 reaches then the interaction goes up to a level and stay steady and when the maintenance is done then the interaction goes down so t 2. So within this time period the operational maintenance stuff is interacting with the system.

Is directly influencing it is primary functions then for some time it will not do anything then after sometime then the t 3 when the next maintenance comes in again the interaction comes in and

you can see that at each time this length can vary depending upon the time of interaction will vary depending upon and what time it is. The classical example is the ship overhaul. The basic overhauls the two simple overhauls are might be cheaper or a shorter duration.

But the major overhaul, the large refit what we call it as that is where it actually take a considerable amount of time and resources and other things. And at the time period the shipyard in which the ship is being maintained is also directly interacting with the system so at that time it is kind of primary stuff. But once the ship leaves the shipyard and then is not coming back at the time is no longer primary.

So, the operational maintenance sometime people classify it as primary sometime it is classified it as secondary. So, it is the only quasi, confusing interaction as part of the systems.

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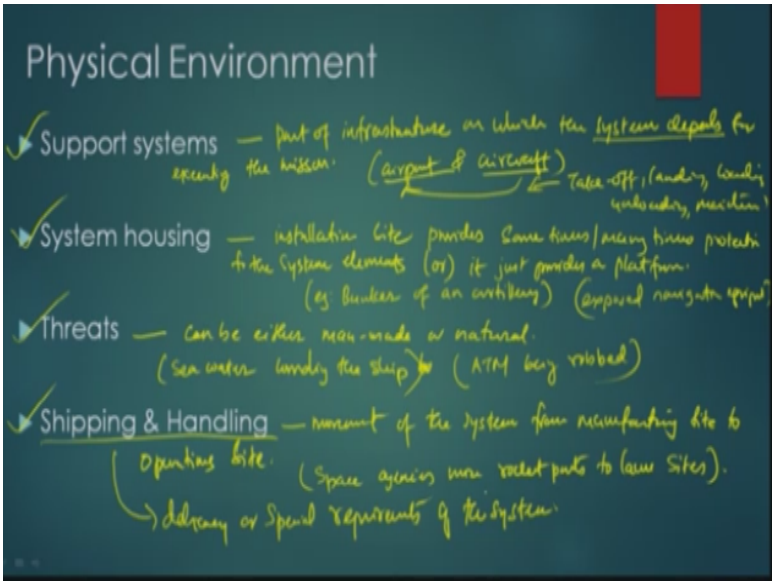

Now, we will talk about the physical environment and the physical environment as I said earlier they provide support to the system mostly. So the first thing that we talk about is the support systems. So what is the support system so the support system is the part of infrastructure on which the system depends for executing the mission. Simple example of this is the airport and aircraft.

So, the aircraft depends upon airport to execute the mission of takeoff, landing, loading,

unloading all those things maintenance etcetera. So, this is the physical environment so depending on different airports the runway will be of different size it will be having different width, different elevations, different operating conditions etcetera. There could be rain, there could be snow, there could be sun, there could be cross winds.

So, many aspects as part of this. But the aircraft as a system is dependent upon the airport to do some of its functions. So, it is part of that infrastructure on which the system depends for executing the mission is what we call as the support systems and that is related to the physical environment of the system. Now, we talk about housing. So, the system housing it is not the houses housing but it is mostly the installation side provides sometimes or I would say many times protection to the system elements.

Or it just provides a platform. So, if you have a like you can think of as a thing that is being installed in a bunker and also just mounted on a ship where it is exposed to the sea and other kind of conditions. So, many a times the housing the installation site do act as protection sometime it would not act as a protection. It just exposes the system to all the possible hazards. So, you can think of the examples.

The bunker will be an example of an artillery gun which offers protection and exposed let us say navigational equipment or on a ship you can think about or gun just mounted on the ship without any protection or casing is another example of a where it is just providing a platform, just a mechanical platform. So that is also both possible. Then we talk about what we call as threats. So there are two ways we can talk about threat it can be either man made or natural.

One of the examples is that sea water corroding the ship. Let us talk about ship as a system. So the system is exposed to it is a natural threat, sea water is corrosive and it corrodes, attack the hull. It keeps on corroding the hull so that is the natural one. On the other hand, is a man made one, you think about an ATM automated teller machine being robbed as a manmade threat. It is not a natural threat.

If a person if he is going to steal money from an ATM because there is money available and he

thinks that he or she can do that. So, that aspect is a manmade threat. So the threats are also parts of the physical environment if the system is operating. So, like if the system is in a remote area the chances of it getting attacked will be much higher compared to when it is near to a place where there is strict security is available.

Then we also talk about it is something called as a shipping and handling because what happens is this is the movement of the system from manufacturing site to operations site. So, you can think about it is the how space agencies move rocket parts to launch sites. So there were so many dedicated specialized equipment that is necessary to safely move the components of the system to the place where the system will be installed and used.

So, that is also an aspect. The reason why you need that kind of a shipping and handling requirement is because of the delicacy or special requirements of the system. So, the support systems the systems housing threads and the shipping and handling these are the four things that we talked about which are aspects of the physical environment of the system and how that effects the, creates different interactions.

And so did not resulting in how different entities react to the system. So, I hope that by this you guys have understood how to look into the systems environment. How to use context diagram to map the environment and the boundaries of the system and how some of the aspects some of the entities how can they create the input output then the threads, then the housing all those aspects how the system interacts with the environment.

And how it impacts the behavior or as well as successful capabilities of the system in delivering the function it is intended to design. Thank you very much and we will catch in the next lecture.