Systems Engineering
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Lecture - 02
Systems Engineering as a profession

Good afternoon today we are into the second lecture of the systems engineering course and today most of our discussion will be about the history of systems engineering. I am Dr. Deepu Philip again from IIT – Kanpur. Today's lecture is kind of important because we need to know how systems engineering evolved as a profession and discipline, so that we have a clear idea where we will be going in the future.

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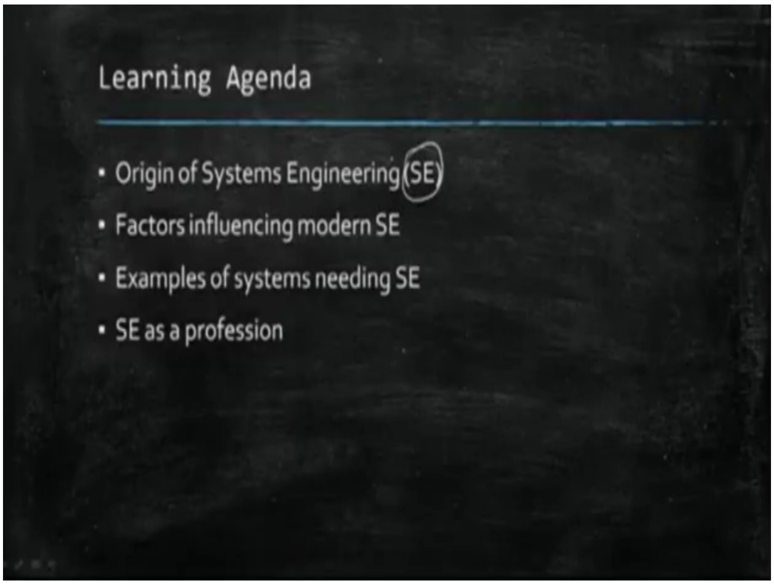

So today's learning agenda is, how did the systems engineering originated. And whenever we see this abbreviation called SE throughout this lecture I will be using SE as an abbreviation for systems engineering. We will also talk about what are the factors that are influencing the modern systems engineering as a discipline and what are the factors that actually contributed to the evolution of the modern systems engineering.

We will also talk about examples of systems, in the systems engineering. Also we will discuss in detail some of the output processes, input, stuff like that. And also have a brief discussion about how does systems engineering work as a profession for students. So the students or practitioners who are actually taking this course you need to know where will you go, go forward in your career by learning through this course. So we will try to cover up that as well.

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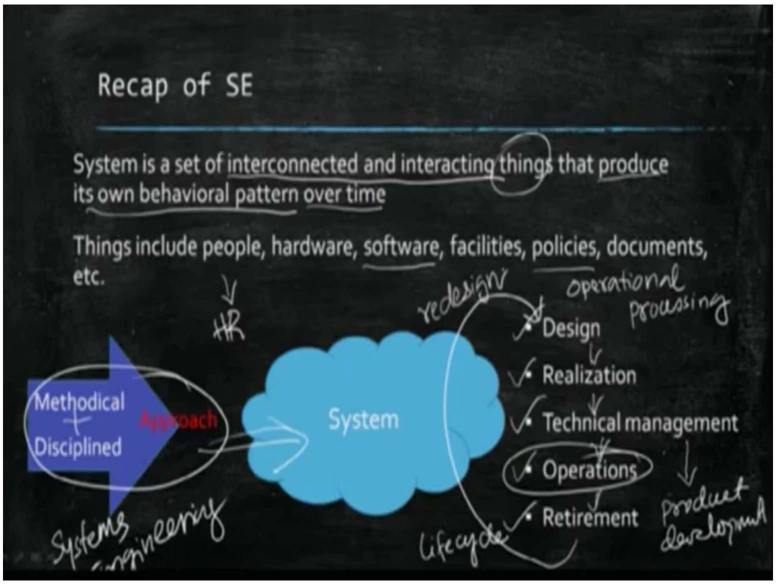

So first we will recap on what systems engineering is of our lecture. We define systems in multiple ways. We talked about how systems engineering definition evolved in the previous lecture. So summarizing all of that and kind of putting it in our own words today we will say is that systems is a set of interconnected and interacting things. We use the word things in a broad sense. So the two major things are interconnection and interactions.

Interconnection means the different components or the things of the systems are connected to each other so that they have to work in unition. And interacting in a sense that the input from one or the output from one thing result becomes input to the other which will kind of either sequentially or parallel trigger certain functions towards realizing the common goal. So these things all interact and interconnect together to produce its own behavioral pattern.

The system will create its own behavioral pattern over time. As the time progresses, as time increases the system behavior will approach what are the desired aspects of the system. In the things what we call as the things which is part of the system, we will define that as or to include people.

People means, it can be trained workers, it can be people who are doing surveys, people who are doing feedback from the customers, people who are working in the field providing the warranty or sort of people human resources, let us call it as human resource in a general sense. So all of the human resources associated with the system is encompassed with the term people.

So, we will kind of call it as HR and hardware includes almost all the machines, circuit boards, tools, all those kind of stuff that is part of the system. Then we also talk about software which is computer programs that are actually part of the system which will result in realizing certain automation and stuff like that. We will discuss this later down the slides today.

Facilities, it involves the buildings, he machining centers, the assembly places, the quality controlled facilities, special purpose applications, all those kind of things are unnecessary to realize the interaction and interconnection of the things. Policies which could be operational policies or it could be other guidelines or processing policies. There are many things that could happen as part of this.

How the system will work? That kind of a document that becomes a policy and documents which is related to, sometimes it could be as a stuff like assembly diagrams. Sometimes it could be like work study diagrams, time and motion studies, product sequencing, all those kind of things as part of those. So all these things work in unition together to realize the behavioral pattern of the system over time.

So you look at it in a little bit more broader sense. Systems engineering, if you write it here, systems engineering it is a methodical and a disciplined approach. The approach is both methodical and as well as disciplined. Methodical means it do have a specific sequence and an order, a method, a process, a script by which you follow the approach or systems engineering and it is also disciplined.

Disciplined in the sense that you actually do it in the way it is described to d. You just do not do it that way you like to do it, but you do it the way it is supposed to be done. So both methodical and disciplined approach together both of these put together we can call it as a systems engineering approach which works on a system for what aspect is, it can be up for designing the system or we are trying to design, designing in the sense specifying the parameters or the characteristics of the system or what is going to accomplish as an output.

Then realization means converting the design to prototype or a product which can be deployed or used by a customer to realize a specific capability or fulfill a need. Also the technical management which means how will you streamline and control the engineering process by which the design gets translated to a usable product. As we said earlier, we are mostly talking in this course about product based systems engineering.

We are not spending too much time on services based engineering. So the technical management we can also think about it as product management or product development management. Then the operations, how is the system works. How does the system gets operated? When the person used to sit in the fields how does the system work or the production system works to realize the product.

All those kinds of things are part of the operations. So it is basically a transformation process where inputs get translated to an output and the operations that are required to translate the input to the output comes under this operations stuff. And finally comes the last part which is called as the retirement because every system after a certain point of time it meets its lifecycle.

So the retirement is related to the lifecycle of the system and when the product reaches or the system reaches its end of the lifecycle, how do you retire the system or how do you take care of the disbursal of the product. That aspect is also the part of the systems engineering. So if you think about it, the phase from the design, to the realization, to the technical management, to the operations to the retirement and certain cases it goes back in what we call as redesign concept.

All of these things come as part of the systems engineering. This is where the multiple versions of the product happen.

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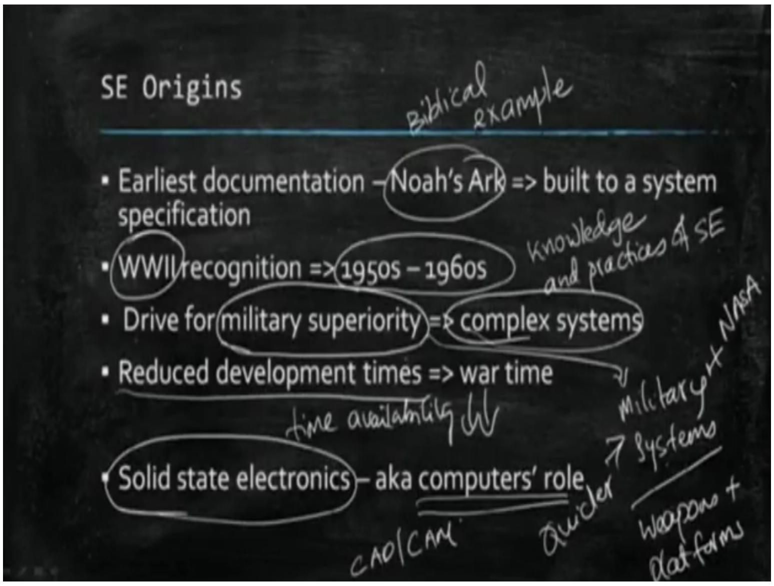

So with that let us talk about the, how were the origins of the system engineering. There is not really clear cut origin declared or defined that this is the day, particular day and time the systems engineering evolved as a field. The earliest documentation, many of the systems engineering touch books and authors and other people do cite this example, this is a biblical example.

Noah's Ark, biblical example where Noah ended up building a big arc or a bit like kind of a ship which was build to a specification which was designed to carry male and female of each and every available species of the world, so that when the big flood happens everybody will be saved kind of a thing.

So this Noah's Ark is kind of what people call it as the oldest documented evidence of a system engineering approach or where the system was build to a defined specification. But biblical examples aside, most of the people agree or most of the researchers and practitioners of system engineering agree with the fact that the world war II is where the systems engineering, WWII is the world war II, where systems engineering as a field started getting its recognition.

So 1950s to 1960s, this is the time period where many books, literature, research publication and all other aspects that are related to systems engineering started to get published, printed and this is where the knowledge and practices start off systems engineering, started to evolve. The scientific knowledge associated, the proper documented knowledge with a scientific approach started developing around in this area.

But by the way in that time period in 1950s and 1960s the initial phases of system engineering, it was driven by, it was driven by the countries or different nation's greed or their want to gain military superiority. How do we gain military superiority over the adversary that was the major question that was going on? So lot of these systems engineering initial development started with military systems which to a large extent you can think about it as weapons plus the platforms for weapons.

Maybe it can be an aircraft, it could be a ship, it could be a submarine doesn't matter, or missiles, all of them were originally developed as part of the, they were the initial products that came out of the system engineering products. And most of the systems are complex because there are many aspects involved in this. There are materials, there is payload, there is control, there is feedbacks, there is corrections.

So all those kind of things you require multiple aspects of engineering, is involved in the development of this military systems. Hence the systems engineering initially was confined to a lot in towards doing military development and plus also in United States NASA was also a big practice of systems engineering. NASA is the space agency, North American Space Agency.

So we say that as all of the complex systems that are associated with military was developed through systems engineering. One other aspect that also drove the systems engineering big time was that, at the time of war you do not have the luxury of time because if your advisory comes up with an efficient product or a weapon then your chances of winning the war diminishes significantly.

Hence the time to develop the product was a big criteria. So once the times were crunch or what we call it as time availability, when they were significantly reduced during war time, so they needed an approach that could actually see the faster or quicker developments of the military systems. So that was also another aspect which forced the development of the systems engineering.

And so even though it was mostly confined to the military field, one of the development that actually made systems engineering to come out of the military realm towards much more of an engineering discipline and starts, spread its wings into multiple other products and systems and complicated aspects was the advent of the solid state electronics or in a simple way to say it is the development or the advancement in the computer technology.

As computer technologies advance, the solid state electronics advance, computation power increased, the capabilities that you would do by doing large number of data analysis, number crunching, doing designs using computers like CAD/CAM all those kind of things, they all facilitated towards rapid design and development of systems, complex systems.

So the computers to a large extent after the initial world war phase where the aim of the systems engineering was to gain design complex military systems to gain military superiority, it translated to design any complex system, the most efficient way possible and the computers actually did facilitate it, actually made the systems engineering much more accessible to simpler tasks.

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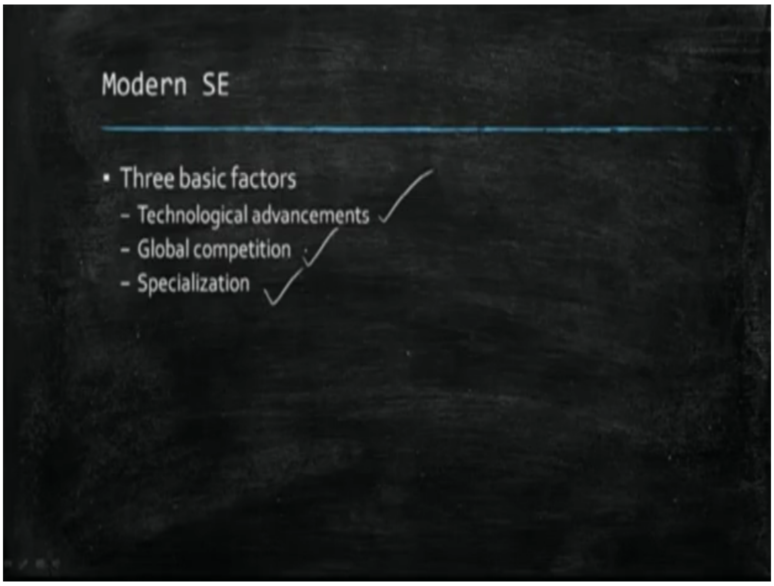

So the modern systems engineering after the advent of the computers and the advancements of it, is basically driven by 3 basic factors, the technological advancements, the global competition and specialization. We will talk about all these factors and how they actually result in the development of modern systems engineering in the next slides.

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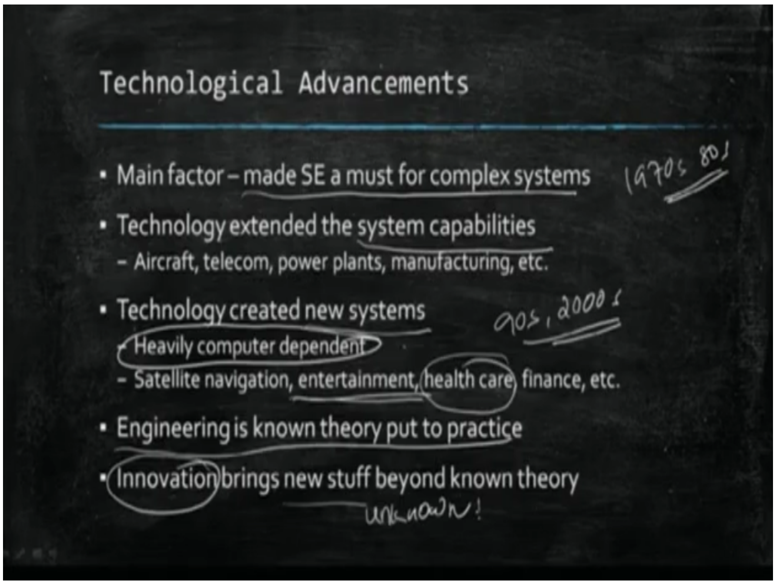

So the technological advancement, we all know the technology now is developing at a break neck speed. The main factors of the systems engineering to a large extent is the rapid technological advancement that has happened. In earlier days when the automated machines or what we call as the CNC machines, computer numerical machines came in, they were considered as the epitome of technological advancement.

So now from there we have moved into what we call as a flexible manufacturing systems where it give kind of the raw material and the product schedule and the machines automatically product those parts and give it like to you, which is almost like a no man required factories kind of a thing. So development, technological advancement to a large extent drove the beyond the world war developments of the systems engineering which is in 1970s and 1980s the systems engineering was driven by technological advancements.

The technology also extended the capabilities of the system. In a simpler sense, the aircraft systems, they were earlier transatlantic flights were a big thing. Now flights that circum navigates the globe is not a big deal. Telecom when original connection, with the wired telephone connections which was actually developed as AT&T Bell Labs and all, was there people were surprised that you could talk to a person who is far away through a telephone, you could hear the voice, it was a big time.

But then with the advent of mobile phones which is landline based telephone has now become almost an obsolete item. Similarly, power plants earlier everybody used during the time of the world war, nuclear weapons were used as a destructive tool. But after which the technological advancement figured out that the nuclear energy can be harnessed for better civilian needs like producing clean power and then nuclear power plants came in and that was one of the other aspects why the technological advancement resulted in engineering of complicated plants like nuclear power plants using systems engineering.

Similarly, manufacturing, earlier aspects of like for example automotive manufacturing to a large extent was skilled assembly, hand build motors. From there specialized machines, tools, robots, painting mechanisms, all those kind of things has put together, has made almost the development or the manufacturing of an automotive to a large extent heavily automated process. We will see some of the other aspects in the later slides.

Similarly, technology also has created new systems. First one is it increased the capabilities of the existing system and another one is it also created new systems. And most of the new systems are created which was in 90s and 2000s. They have been heavily computer dependent. Like earlier in the land based telephone, the presence of a chip was not an important thing, there were actually no chips present.

Whereas in a mobile phone you are talking about a processor, the memory, it is almost like a mini computer that you carry around in your pocket in which you can do lot of daily activities. Similarly, other systems that earlier when you have to go from a place A to place B nobody even thought about a system called satellite navigation or what we popularly call it as GPS based system, global positioning system.

Nobody thought that satellite could be used for navigation or help you to go from place A to place B, find your route. Similarly, entertainment, when Edison developed the projection or the movie projector it was considered as advancement in entertainment, but with the advent of the digital technology and satellite and other things the concept of the tape and the movie reels and other things were replaced by digital movie systems.

So the concept of the entertainment with the new advancement in sound systems where you could actually feel, the people call it as 3D or virtual reality whatever you want to call it, but entertainment also with advancement of new system has gone much higher. Healthcare earlier it was x ray films, now almost all the healthcare is in a tablet in front of the doctor. When the time you reach his office he kind of knows your history.

So the advancement of the imaging, another aspect of increase the assurity and as well as capabilities of the healthcare systems, in earlier days, finance was mostly dependent upon reliable local branches and where you have to go to foreign countries you are expected to carry the foreign currency or something called as traveller's cheque.

With the advances in computer systems and as well as the databases and the interconnectivity internet and stuff like that, you could now come up with plastic money which you could carry like a credit card in your pocket which you could take it anywhere across the world and then do the needful. So the new systems development also bought in complexities because most of the time engineering is kind of in the simplest way you can put it is, you kind of know the theory and you are trying to put the theory into practice.

But when new systems or new technologies are created or innovated, this is the better phase innovation, creating better technologies which kind of results in new stuff beyond the non theory, so when the new stuff is available which you have lot of unknowns or you are not completely sure about the theory behind, then to develop a system out of it, you require cheques and balances. That is also one of the major aspects of systems engineering.

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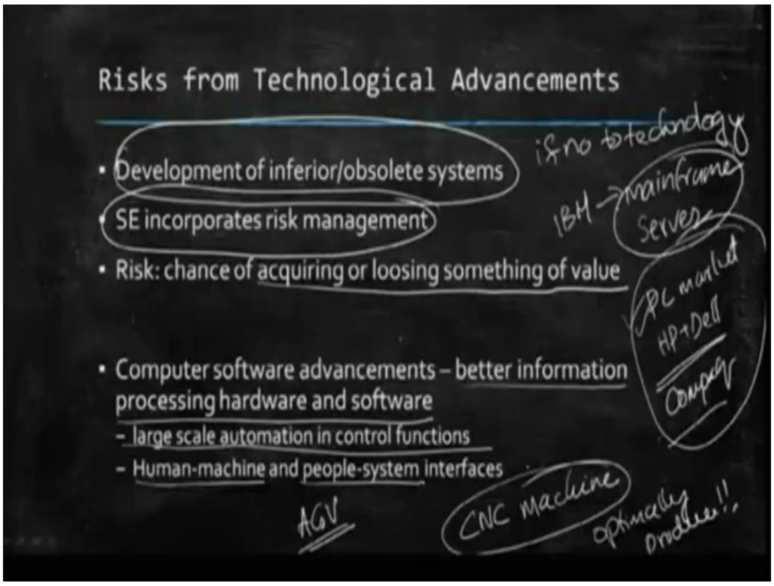

Also the technological advancement that we talk about, it is not without its own risk as well. We need to know the risk of the technological advancement. One of the major risk that comes from is, what happens if you do not embrace technological advancements. So if no two technology, if that is what company does or an organization does then they do stand the risk of developing inferior or obsolete systems.

Some of the public sector companies in India are good examples of this where the sluggishness in adopting advanced technologies have resulted in developing obsolete systems. So an organization if it needs to be staying ahead of the competitors and develop products which the customer wants or the customer needs then they need to embrace technological advancement as quickly as possible.

And stimulate those technological advancements into their organization. Also, systems engineering does beautifully incorporate the risk management, concept of risk management into the development of a new system. So risk in a simple way to define at least the chance of acquiring or losing something of value. So when we talk about acquiring or losing something of value, you could either gain or you could lose, it could be both.

So if you do not embrace that capability like an example it is talked about how IBM as a technological giant refused to get into the personal computer market where they stayed with the servers and the mainframe systems. So the IBM focused on mainframes and servers and did not give too much of focus on the personal computers resulted in the PC market to a large extent dominated by companies like HP and there is another one.

I am forgetting the name but Dell, stuffs like that or Compaq was another example. So these companies who focused specifically on PC market or a personal computer market ended up growing way much better and becoming more profitable than IBM because in the later run, the number of units that were sold in the PC market were way much higher than the mainframe and the server market. So that is actually the opportunity lost in not being able to tap that market, is the risk the IBM stood by not embracing that technological advancement.

Similarly, another advancement we also need to discuss about it is the software advancement. From the simpler languages like FORTRAN and Pascal, which were mostly text based stuff and even hi-fi or high fidelity user interfaces where of dream, the development of the better information processing in both hardware and software are helped in one of the major things which is called as large scale automation of the control functions.

In the earlier days of systems engineering, you could not think about something like a CNC machine. So you load the work piece, you put the tool and then you give your program, computer program which the machine follows which decides when to cut, where to cut what is the depth of the cut, what is the feed rate, how much of the coolant to be used, all these aspects taken care of by the system automatically, not a human being standing there and doing it so that you could actually optimally produce.

That is one thing that was never thought through, but the advance in technological systems both hardware and software and computer systems have made CNC machines reality. Now we have much higher versions, higher capabilities of CNC machines. Nobody even thought about what we call as AGVs, automated guided vehicles which could transport one part from one machine to another.

We all thought we would require a human being to move a part from one machine to another, but now AGVs are available. So this large scale automation has brought in lot more advanced capabilities in the system but it also got its own problem. You have a human machine interface and as well as you have people system interface. These interfaces which were not there in the earlier system have now realized because of the advancements in the automation system.

So earlier the skilled worker was supposed to stand in a machine and work where as currently skilled worker is supposed to supervise the machine and see that it is actually doing, executing the program as per the CNC program that is loaded on to the CNC control. So the new interfaces became another concept of, another aspect that systems engineering needs to be worried about.

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Then we will talk about the second factor which is the global competition. So this is the second factor, we were talking about the technological advancement earlier. So obviously the first thing that actually drive development of new products or new technologies or new systems is a pressure from potential advisories. Classical example is that, the country, any country if you take they have a list of friendly nations as well as adversary nations.

And depends up on what all technology the adversary has, the country try to develop capabilities to compact the technologies or systems that the adversaries have. So another example of this is the competitive contracting. So when this happened, like when the Indian market was open to the global population then the public sector companies who enjoyed the License Raj concept had to face a stiff competition and technologically advanced competition from across the globe and some of them actually did falter.

So the competitive contracting, when you are going for a globalization where much more technological advancement happens across the globe, then this becomes a problem. We also can talk about the first mover advantage. If the competition, if you come into across the market, when Apple came up with this smart phone, when they incorporated things like capabilities to browse internet, have a camera, torch light and music system everything into a phone.

People made fun of it, I mean who would do this? But pretty soon Apple introduced the concept of smart phones which to a large extent has changed the way in which people start using mobile phones. Similarly, cost effective. Everybody knows about the AMD and Intel who are the largest chip manufactures in the world. Chip means I am talking about processors and how they are cost conscious.

See, if you are a cost conscious person, you might go with certain process in AMD, if you are a over clocking person you might go with AMD. But let say if you are looking at number crunching then you might go with an Intel processor. So depending up on different applications and with financial considerations in mind, you might choose one product over the other.

And also another aspect is when the systems became more complex, more things were added to the system. The requirement of the funding, the financial requirements also started going up significantly. So the project which could earlier in one go, you have to do it phases now. So the phases or making it into parts, logically manageable parts are another aspect of the systems engineering.

Finally, there is a competition between performance cost and schedule. You would want the system to do everything at the best performance, also you want it at the lower cost and you also want to develop it within the required time schedule. All these three are conflicting in nature and it is quite hard to realize all of them, realize all is hard. So you compromise and systems engineering allows you to decide when to compromise and what to compromise.

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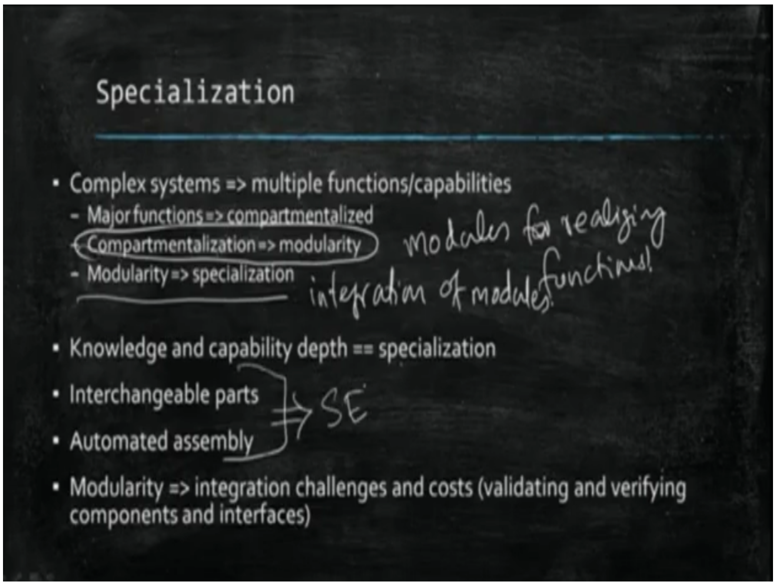

And the last part about that we wanted to talk about is the specialization. The specialization is to a large extent depends upon as system complexity increased, the systems are capable of doing multiple functions at the same time or multiple capabilities. Earlier the mobile phone was supposed to be used for contacting somebody, it was supposed to do the concept of telephoning someone.

Now the phone is, it also manages your alarm, it manages your calendar, it manages your email, it has started doing the healthcare or remote, monitoring your blood pressure, blood sugar all those kind of stuff. It is now a global positioning system or a mapping or a guidance based systems.

So all these capabilities, when you have complex systems with multiple capabilities combined then lot of the major functions need to be compartmentalized because the requirements of a GPS or a navigation system where GPS is needed and the requirement of a mobile phone where you are just making a telephone call to someone are two different things. So both these applications require compartmentalization.

So the compartmentalization is usually achieved through something called as modularity. You make things module. Modules for realizing functions. So when you have modularity then specialization is realized modularity. So in a simplest sense when you have too much of things which are modular, they all need to be integrated together. So the systems engineering when you have modularity, the integration of them, integration of module becomes another aspect, another factor that drove the development of systems engineering.

To a large extent this interchangeable parts and automated assembly is required systems engineering. These two things to a large extent drive the systems engineering to its current state of expertise.

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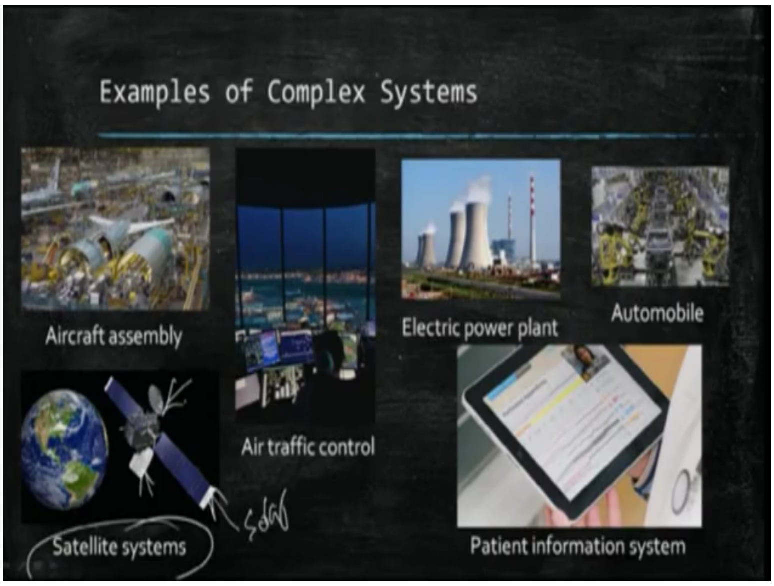

Some of the complex systems, this is kind of our last slide. We will conclude here. One of the examples of the complex system is the aircraft assembly as I mentioned earlier, aircraft include materials, we have a propulsion system in the form of engine, it could be a turbo propeller or a jet engine. You have a fuel system. You have a control system. You have lot of decision to make like if it is a passenger aircraft you want to reduce the weight.

So one way to do it is do not put any cushion on the seat. But the passenger who is sitting on the seat will not be comfortable, so you want to provide some cushion to that. So then people were like why do not we make the cushion in such a way that it could be also used as a floatation device in the make of a missile. So combining functionalities and other kind of things, people started making aircraft much more lighter.

So that, it could travel much more longer distances. So, similarly, a traffic control is you have aircrafts which are landing, taking off, taxiing, parking, maintaining, all those kind of things going on crazy in an airport. So, air traffic control does provide a complicated system which gives a bird eye view of what is happening in the airport. Similarly, the patient information system is another example which I mentioned earlier.

Automotive manufacturing you can actually see how different robots buy in itself are manufactured in the automotive. Electric power plant I mentioned about the nuclear power system, how it was being developed as a system to crack the, harness the civilian was the clean aspects of nuclear energy. Similarly, satellite systems, how we can see the solar panels, then you can see the payloads coming right here, the communications, all those aspects are part of such complex systems.

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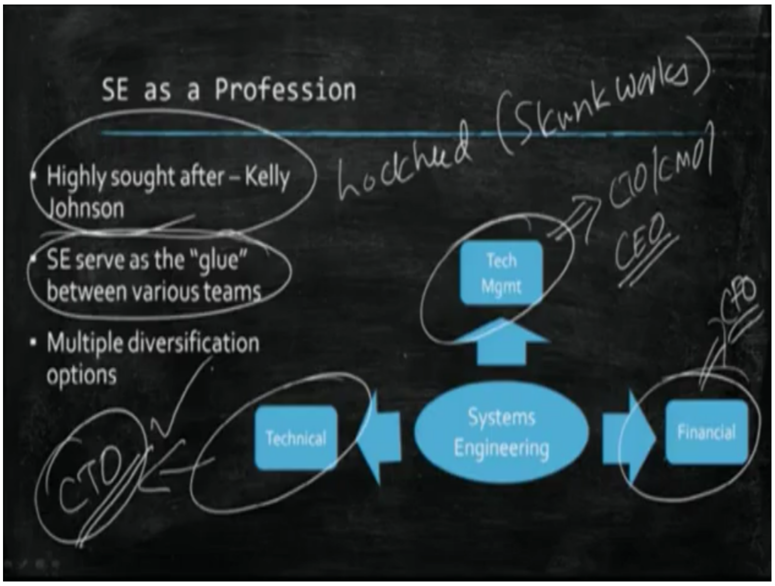

So, as a profession, system engineering as a profession, where do you go from there in as a systems engineer? One of the things I suggest you to do is read the history of Kelly Johnson or Lockheed Martin which is called as Skunk works, of what he did and how he kind of converted systems engineering into a profession, a much respectable profession, how he was revered as one of the most successful systems engineer.

But at the end of the day, a systems engineer is supposed to be the glue between various teams. He is the one who combines all aspects of the systems engineering together and it to a large extent, a person who is trained in systems engineering you have multiple diversification options. One could be into the financial, another could be in the technology management. Third one could be the pure technical.

So this one will probably go into becoming the CTO or chief technological officer or whatever. This could go into what we call as the CFO, the chief financial officer because after developing too many systems you know how much is going to cost and how funds can be managed by the tech management to a large extent, you can become what we call as a CTO, CMO and then also the another thing is you can be the chief marketing officer.

Another example is what we call as the CEO how you could actually manage a technology company and see how Kelly Johnson was offered the job of CEO a multiple times, but he chose to remain as a CTO for quite a lot of time. So with that today we will conclude today’s presentation. We will see in the next presentation on advancements of systems engineering. Thank you.