Process Control -Design, Analysis and Assessment
Professor Raghunathan Rangaswamy
Department of Chemical Engineering
Indian Institute of Technology, Madras
Introduction

Welcome to the first lecture on process control design analysis and assessment my name is Professor Raghunathan Rangaswamy and I am in the Department of chemical engineering AT IIT Madras. The first few lectures are going to make them very general, explain some important ideas in process control without introducing too much mathematics and after this first few lectures we will dive into the course in its real detail.

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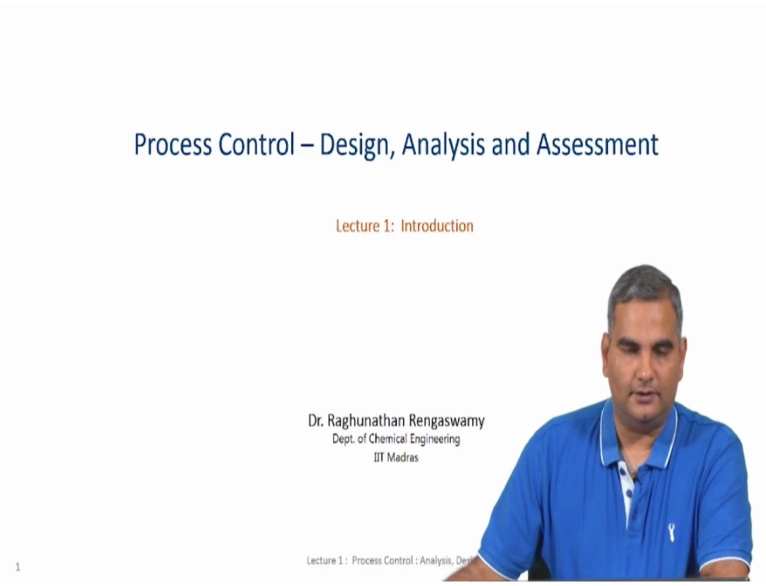

Many of you might have seen the introduction video for the course.

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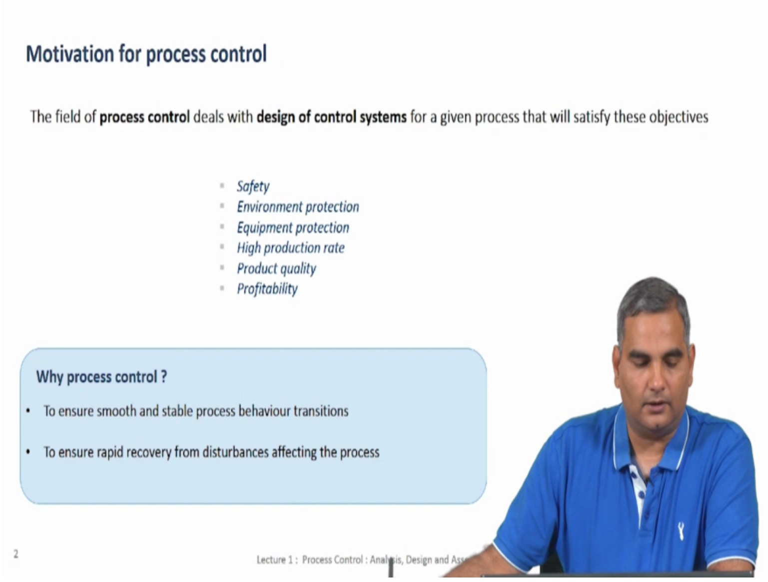

There we talked about the motivations for process control and we said the field of process control deals with design of control systems for given processes. Basically whenever we talk about process control there are certain objectives that we want to satisfy. We want to run the process safely, we want to render process in such a way there are no bad effects on the environment.

We want to run our processes in such a way that equipment that is used in this processes last for a long time. We want to produce as much material that is of interest as possible while maintaining safety, environment regulations and equipment protection. And we don't want to just make lots of material we want to make lots of useful material which basically means we want to make material or products of high quality.

All of this in fact of course the profitability of whatever we are doing and how do we do all of this for a process when there are things that are really not in the control of people running the process? So for example if you're running a process whether it is going to rain today or tomorrow it's not in your control, the temperature of the surrounding is not in your control, the humidity is not in your control and every process basically takes raw material and then does something with it and convert that into useful products.

And in many cases while you might ask for raw materials of certain quality you cannot expect absolute quality. So in terms of the quality of raw materials things could be different, so you have to take all of this into account and still be able to run your plant profitably without damaging the surrounding and the environment. So process control is very critical component for us to be able to do this.

So we might say if we want to ensure smooth and stable process behavior, we need process control if we have to run the process very well even with disturbance is occurring then we need process control.

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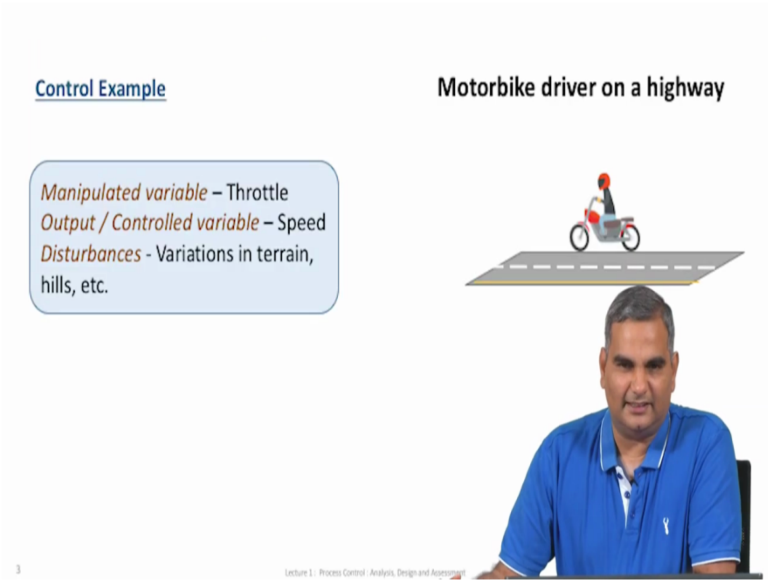

This is an example of very simple example, an engineering example not necessarily chemical engineering are mechanical engineering, it is a simple example that we see in day-to-day that I had used in my introduction video to explain process control. I'm going to take again the same example to kind of interviews some terms that we will see again and again in this course, so I talked about an activity that many of us have undertaken which is like a motorbike on a road.

And with talked about this before we might want to ride a motorbike at a certain speed we might say is what we want to have because that's where it's more fuel efficient or it could be just that it's a personal preference I talk about this already. So you might want to really drive little fast with the wind blowing on your face or you might want to drive little slow to take in the scenery surrounding (())(3:49).

So what we really want to control in this process is a speed of the bike and what we have to manipulate control the speed so whenever I want to set the speed at some value that has to be something that I can manipulate, so that I can increase or decrease the speed as might be the case. So the manipulated variable in this case is the throttle. So we use the throttle and then if you want to speed up we increase the throttle and if you want slowdown we shut down the total and so on.

Now imagine that is you're driving on the road and let's say you are driving at the speed that you're very comfortable with, so let's take the scenario and then ask the question as to why I might need control? So to answer to this question is going to tell us there are 2 types of control that are very important from controlling processes and so on. The very first control is because of the following.

You're driving at the speed you want, however suddenly you see a vehicle in front of you at additions and what you want to really do is you want to overtake this vehicle because it is going at a slower speed than what you are going at. So one thing you might to is you might move the other lane and then increase your speed till you overtake this vehicle and come back to your original lane and then go back to the speed that you were doing.

So here the change in the speed or the change in the control variable is something that you have decided and you want to make this change, okay. So this is one type of control. So everything is going a plan, the output is at its value but certainly you want to change the output to a new value. Now there is another situation where let's say you are going on flat terrain and suddenly the road starts sloping up.

In which case you're holding your throttle at the same point but you're not attaining the same speed that you attain before. So this is what we call as disturbances which are the things that change the control variable from its said value even though you are holding a manipulated variable at the same value. So this is outside affair control you cannot control the terrain of every road that you are driving.

So things that are outside of our control we call as disturbances, so here variations in the rain hills etc. So there is a distinct difference between these 2 control activities. In the first case, while everything was all right I actually kind of water to increase the speed in anticipation of something. It might be an anticipation of the vehicle ahead of me at quite a distance or it could be in anticipation of you know better scenery going to show up, so I'm going to slowdown and so on.

So this is something that I'm interested in doing to change the control variable, the other case is where there are things that are outside of my control which is changing automatically control variable and I want to do something about that.

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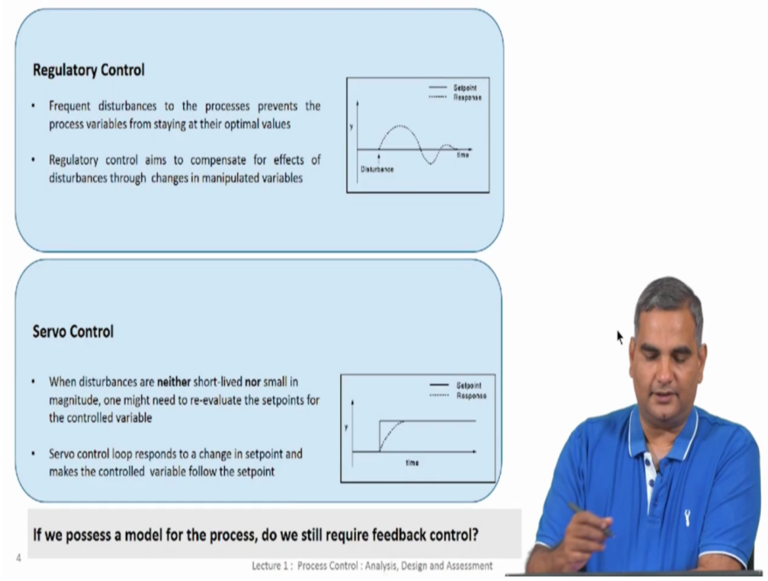

So the first type of control is what I am going to call as regulatory control which is the most important type of control that is usually done in process plants. So this relates to actually disturbances and the control variable changing according to the disturbance and then you do something with your manipulated variable to bring it back to its original value.

So if you take this picture here, so here we are plotting the output variable let's assume the said value for this output variable is given by this line and if you look at the initial portion of the curve the output is at the set value. Now this is like driving on a flat terrain at a particular speed at some point let's say the speed increases or decreases. So for example if you have a slope let's say the speed increases.

Now what you want to do is your aim is to be right at this set point but because of the disturbance output has changed. Now regulatory control is one where the manipulated variables change in response to this disturbance, so that this control variable ultimately comes to its set point value. So you might have certain amount of time before the output variable comes to its set point value.

Nonetheless after a while the output comes to a set point value. So this type of control which is in response to disturbance is what is called regulatory control.

Now look at this picture here this is different from the other pitcher and the difference is, in this picture the set point was always at the same value but up to here the output is at a set point value. Now what you're doing is, you're actually asking the set point to be moved to a new value. This is out of your own interest there is no disturbance here which has changed the output you're asking for a new set point to be followed in which case you want the manipulated variable to be able to make changes such that this output after a while starts following the set point.

So this type of control is called Servo control where we expect the controller to follow the set point where the set point is changing. So you can see the difference between Regulatory control and Servo control. Now these are 2 important concepts that we use in control quite often and you can imagine several examples of this in real processes, supposing you are producing several products in a chemical process.

And each product is selling at certain rice and there is a certain amount of effort that it takes to make a certain mix of these products. Now depending on the market demand you would have some set point for all of this product. Now everything is going great and you are producing these amounts, let's assume at some point the market dynamics changes and the product which was not selling for a very high cost suddenly starts selling for higher cost.

Then what you will do is, you will try to change dynamics of this product. So you're going to make more of some and less of some. So your originals set points are going to change and you are going to try and follow you set points, so this is Servo control. In the same case for example you have certain quality of these products and the quality of these products depend on what comes into the process.

Let's say there is some change in what comes in the process, so that's like a disturbance in which case you still want to maintain the same product quality is before that is you want to reject this disturbance that comes through the input material then this would be regulatory control. Now we might ask question as to if I have a model for this process, can I do this Servo control and regulatory control?

In other words simple question is if you know there is a particular throttle position at which I go at a certain velocity then is it just a question of moving from one throttle position to another to be able to do this control is an important question to ask.

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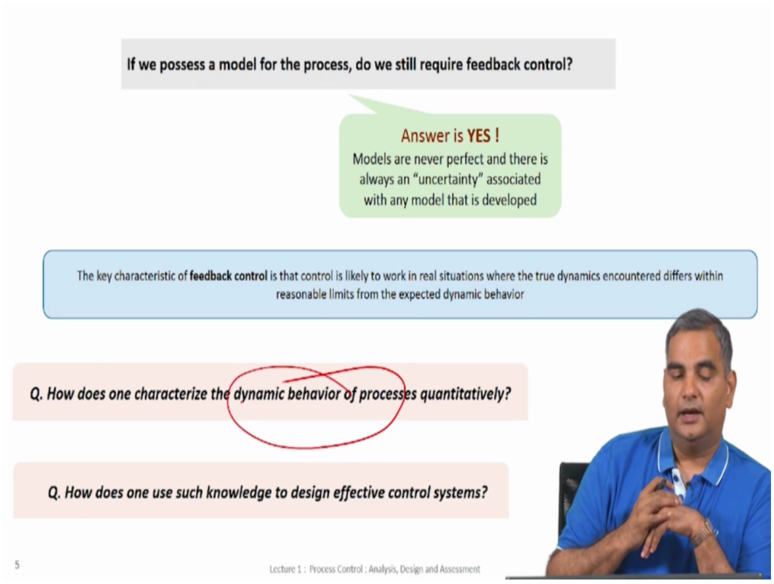

Now the answer to this question is even if we have a model for a process we still require what I'm going to call as feedback control, we will explain what this feedback control is. This is because whatever models that you come up with a particular throttle position alligator certain velocity it is never perfect, models are always desert with some error or the other, so there are some uncertainty always associated with models.

So even if I'm able to develop a model for how the control variable would behave with respect to manipulated variable, you still need this notion of feedback control which we will explain subsequently for you to be able to efficiently do Regulatory control and Servo control. So the questions are then first is, since we talked about a model, how does one characterize the behavior of this processes using a model quantitatively?

So that's one question that we ask and the 2nd question that we ask is how does one use this knowledge to design effective control system. So these are the 2 fundamental questions that actually we are going to answer through this course. Now I want you look at some of the words here just now I was explaining the bike example I said maybe we have a model where a particular throttle position gives you velocity, right?

So that type of model is what we would call as a static model where we say, okay if I give your total position here is a velocity. So that's like a static map but in reality when you are driving these bikes what you're going to do is, you're going to move your throttle from one position to another and for all of us who have driven motorbikes we know that, if let's say I start my throttle and take it to full position I don't get to the final velocity right away.

So it takes a while before that final velocity is reached. So even though I have instantaneously changed my manipulated variable, the effect of that manipulated variable and the control variable is not instantaneous. It takes a little bit of time before this effect is seen in the control variable. So the time aspect of the change of control variable, whenever there are changes in the manipulated variable is what we call as a dynamic behavior of the process.

So this is an important concept from process control and what they need to do is we need to be able to characterize this dynamic behavior of the process, only if the characterize the dynamic behavior of the process would we be able to do good feedback control as we will see, as will go through this course. So whenever there is a process one of the questions is that we need to answer is how do I model this process?

Quantitatively the dynamics of the process wherein we mean if I change manipulated variable how would it affect the control variable from a time behavior? And once we have such a model the next question that we would be interested in is, how would I use such a model to design effective controls systems.

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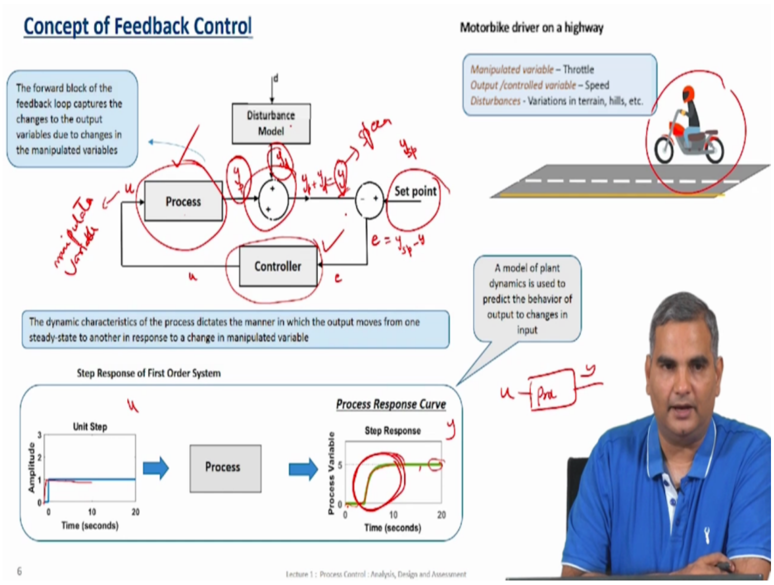

So here is where we bring this notion of Feedback control for the first time. I'm going to stick to the same bike example for a few more slides to explain this concept of feedback control this blog diagram here is something that we will see several times through this course. So let me start explaining this blog diagram. Before I explain this blog diagram let's think about the feedback control that we actually do as humans when we ride a bike.

So let's assume you are riding a bike at a certain speed and then there is a certain incline and then you start going over the incline and then the speed comes down. At this point the person driving the bike who is the controller, basically senses that the speed has come down and you could sense the speed has come down to just physical means or you could look at the ODO meter reading.

And then see that I was driving my bike at 60 km/h suddenly I'm going down to 55 a little bit later I'm going down to 50 and this change is because a disturbance which is incline that has come up and this is what we showed in the picture in the last slide. Now clearly you want to be at 60 km/h and you are sensing the speed is not at that level. So what you do is basically use a look there is a difference between where I want to be and where I am at and that difference in some sense drives how much of manipulation I do.

So for example if it is a very very slight incline the speed has come down only a little you will see that there is only a little change in the field. So you might increase your throttle position by a little bit. However if it is a very steep incline the speed is really dropping you are going to move your throttle to the other side very fast. So notice that as human being the controller here you are looking at the difference between the control variable values that you want the control variable to have which is what we are going to call as the Set point.

The value that the controller variable should have and the actual value that the controller variable has you see the difference and that error drives your manipulated, right? And the controller here in this case is the human being and human being says okay it's very different from the speed where I want, so I'm going to increase my accelerator or the throttle to large amount or if it's a small difference, smaller amount and so on.

So this concept which we are very good at naturally how do we translate the industrial systems, right? How do you think about the mathematics of this and industrial system? Remember we do several several activities in a feedback control in a very efficient way. Any game that you are playing, if you're playing tennis there is feedback control all the time. So you know that there is a ball and your racket has to go and hit the ball and you know the desired position is close to the ball but if your racket is far away then your legs move towards the position and so on.

So there is very complicated feedback control that is happening there, which will do seamlessly and effortlessly, how do we bring those ideas to real processes is a key question that we are going to ask? And the word feedback is because the actions are taken based on the feedback which is a error feedback which is a difference between where I want to be and where I am actually at.

So where I want to be is the set point where I am actually at is the actual value. So when you start doing this mathematically you start doing this simple blog diagram. It will take us a while before you get comfortable with this diagram because there is something called a disturbance model, there is something called a process block, controller block here and so on.

However there is only one bike here, right? So how do I connect this bike to these is important question and the way we will do this is, we will first talk about this block diagram and then tell you what these are. And as we go on to the modeling exercise you will see how we think about these blocks and what are these and so on and how do they come about to be in this form is something that we will describe as we go through this course.

For now let's look at this blog diagram let's first understand what each of these elements mean. How do I translate this bike to this elements is the next question but let's first understand what these elements mean and then as I said before when we actually do modeling we will see this again and again, so that you get very comfortable with this blog diagram.

So this blog diagram basically says the following, so what you do is, you start with each of his lines, so I go through this and then explain this blog diagram and we will make more comments about how I might able to separate this process and disturbance as 2 blocks and so on later. So those are based on principles of linearity and so on which will come back to later in the course.

So for every one of these lines in this diagram so I can associate a variable so for example I'm going to associate a variable u here and this u is, what is the manipulated variable that we have talked about quite a bit till now. So this is the manipulated variable. Now whenever there is a block what it says is this manipulated variable was through whatever is the process block which is actually a mathematical block, we will come back to describing this later and there is an output which comes out.

So an input goes and there is an output from the block, how this input is converted to the output is something that we will see later but as far as we want to understand now, we will just say that this is the output y subscript p and p stands for process here and I will explain this subsequently. Similarly if you look here there is d, which is other word that we have been using which is called disturbance.

And when that goes to the disturbance model you have what is called yd, okay. So every blog has an input and an output, Okay. So this blog has u as input y subscript p as output and this blog has d as the input and y subscript d as output. Now whenever you have circles like this and signs like this, so basically what it says is the circle takes as many inputs as you can give it in this case 2 and it tells you what you should do with these 2 inputs.

So in this case it says okay there is one input here, there is one input here, add them up and that output of the circle. So here I'm going to have yp plus yd and this is going to be my total y, okay. So I will explain this with this bike, let's hold on for some more time. Now similar to this blog this is another circle and it has 2 inputs, so one is this y, so let's call this y set point it says take the difference between this y set point and y and then the output here is the error which is going to be equal to y set point minus y.

And this error is what goes as an input into the controller and it's the same line, so I have the same e here and the output is u because it's the same line here. So now you notice this, this controller takes the error as the input and then says what should be the manipulated variable and clearly that's what we saw in the bike. So I told you if I want to go at 60 km/h and I find that I'm going only at 55 km/h then there is an error of 5 km/h which basically is what makes me move my throttle.

So that controller tells you what the output throttle position should be, so you can understand this controller. In this example this controller is really the human being that is driving the bike. Now this looks a little more complicated it says I have only one bike but why do I have 2 blocks, so you might want to think of this as this, right? So both of these actually represent the bike.

This blog represents the effect of the total on the speed, clearly y is the speed. So what we want is just the speed. Now this blog represents the effect of the throttle on this page. So for example if you increase the throttle the speed will increase, if you decrease the total the speed will decrease and so on but the speed of the bike as we all know does not depend only on the throttle.

I could be in the same throttle position and I will be going at a certain speed on a flat road and at the same throttle position if the road is slightly inclined I will be going at a lesser speed, so just the throttle position alone cannot model speed the disturbance in this case for example the incline of the road if you think of that as a disturbance that also dictates what the speed is.

So you might want to think of this as 2 effects that have a final impact on the speed and since at the initial portion or for the large portion of the course we are going to talk about linear systems. Whenever you have things that are affecting together, if it's a linear system the total effect will be the sum of individual affect.

So for example the speed mathematically we are saying is a combination of the effect of your throttle and the effect of your disturbance. So that you can actually model both incline and the throttle position on speed. So that's a reason why we have this. Now this is a critical circle because I am able to just add these 2 effects to find the speed because I assume the process is linear.

If the process is not linear then this would not be a valid assumption, so that's an important thing to understand. So this is your basic feedback diagram where I show the output by comparison with a Set point the error driving the controller and the manipulated variable driving the process and the disturbance also driving the process and because it is a linear process this y is a sum of yp plus yd, okay.

Now if you think about this in a little more detail, so for example I want to just take this portion and then say, okay here I have u which is going into a process and I get y as output, so what does this mean? So here is an example, so this is your u and this is your process and this is your y which we call as the process response group. So here in the schematic we show that if you suddenly increase your input by certain amount what is called as step change how is your output going to vary.

So it might very something like this, so to get the model to say that if I change my input this way the output will change this way is the mathematical model of the process. And you can say that this will be very consistent with this bike example, so for example if you are at that particular throttle position and you go to your throttle position the speed immediately does not change.

The bike picks up and after a while it goes to steady speed, right? So it was at this speed and then you change the throttle position, at the new throttle position this is the final speed but it takes a little while for the bike to pick up to go to the new position. So this is what we talked about as a dynamics of the process, so just because I change my manipulated variable instantly from here to here my output does not go from here to here instantly.

It takes a while for the output to go from its value to the new value and this model is the dynamic model of the process. How do you mathematically right equations? So that this dynamics is captured is something that we are going to see through this course but I just wanted to give you the basic idea of how all of these things work together.

So to summarize there is a dynamic model for the throttle with respect to speed clearly there is also a dynamic model for the speed with respect to incline. So for example if you're going on a flat road and there is a certain incline the speed does not go to a low value right away, so it takes a while to go to the low value and that is basically the dynamics of the disturbance and because we assume that the underlying process itself is linear which is just an assumption.

We say that the total overall effect of the manipulated variable in the disturbance variable can be added together and represent the final output, okay. So there will be a dynamic model for the manipulated variable, there will be a dynamic model for the disturbance variable and there will be a controller which is basically saying the difference between the actual output value and the set point and using that it is going to say how I manipulate my variables, okay.

So in this course what we are going to see? Is we are going to see how to build this disturbance model, how to build this process model and how to develop these controllers, so that whatever activity that we talked about here for this bike we can take it to engineering Systems and let computers do this control for us.

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Now if you notice in the previous example there is one manipulated variable which is at throttle position and then there is one control variable which is speed but in real plans there will be multiple inputs and multiple outputs. So as I mentioned before in the introduction video we still need to think about how we will do this when I have multiple inputs and multiple outputs.

How do these ideas translate to multiple inputs and multiple outputs? This is something that we are going to deal with in detail. So what I will do is, in the next lecture I will talk about how we can think of this multiple input multiple output control from the viewpoint of single input single output control. This is because of the general questions is that whenever you do an undergrad control class or undergrad material?

Almost about 75 to 80% of the time we typically talk about the CSO control but we always know that in real industrial processes it is not CSO controls is going to be MIMO control. In fact even in the bike example if I complicate it a little bit more I can think of 2 inputs. So for example the speed is not only based on your throttle but it is also based on the break that you apply.

So if you throttle and apply your brake at the same time then the speed dynamics will be different from if I applied by brake alone or throttle alone. So even in that symbol example there are more than one inputs that actually affect the output. So and then even for such simple examples it is MIMO control for large complicated processes it is definitely going to be MIMO control.

So one question that can arise is, why we are studying CSO control (())(30:00) when really most processes are MIMO control problem is broken down into CSO control problems without losing much of the aspects of MIMO in very simple cases. And then of course the 2^{nd} part of the course as I mentioned before we will really look at the MIMO control in its entirety.

So that's an important aspect of control that we need to keep in mind. I also want to point out here actually in most real processes such as the one that is shown here. In fact this MIMO control problem is largely address as multiple CSO control problems there will still be many many CSO loops in this facility which will be doing its job very well. So we need to really understand how is this CSO control you know universal or it has such universality that it is able to work in about you know 90 to 95% of cases even in real industrial systems where there are multiple input multiple output effects.

So that is something that we will talk about in the next lecture. So I will come back in the next lecture and pickup from here and then explain how the MIMO control is broken down into several CSO control problems without losing the essence of the notion of MIMO control and later we will see MIMO control completely as MIMO control itself. So I hope this introduction set the tone for what is going to come in the future lectures. I will see you again in the next lecture, thanks.