

NPTEL Online Certification Courses
COLLABORATIVE ROBOTS (COBOTS): THEORY AND PRACTICE
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Week: 01
Lecture: 03

The Process of Risk Assessment

Welcome back. So, in this lecture, I will introduce you to the process of risk assessment.

Overview of this lecture 

- Why do we need risk assessment?
- Risk assessment and avoidance: Using ANSI/RIA TR R15.306-2016
- Prerequisites of Risk Assessment
- Risk Assessment: Assessment of Injury severity, exposure and avoidance factors
- Determining the Risk Level using SEA Analysis
- Sample Risk Assessment Data Template
- Risk Reduction Measures



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So, the overview of this lecture is as follows. We will discuss why we need risk assessment. Risk assessment and its avoidance using ANSI/RIA TR R15.306-2016. This is the standard. We'll discuss the prerequisites for Risk Assessment: Assessment Of Injury severity, exposure, and avoidance factors. We'll discuss Determining the Risk Level using SEA Analysis, a Sample Risk Assessment Data Template, and Risk Reduction Measures.

Why Risk Assessment?

For collaborative robot environment



- ▶ Safety: Cobots work along side humans, and ensuring their safe interaction is paramount.
- ▶ Collision avoidance: Cobots move within shared workspaces.
- ▶ Task complexity: Helps to determine appropriate safety protocols.
- ▶ Cobot design: Helps to determine reach, payload capacity, and joint flexibility.
- ▶ Human-Cobot Interaction: Considering factors like proximity, force exertion, and speed during collaborative tasks, helps to decide on safety measures and training.
- ▶ Work Area Analysis: Optimization of layout, lighting, and obstructions ensures safe operation.
- ▶ End-of-Arm Tooling: Assessing the attached tools ensures the safety of humans and the robot.
- ▶ Continuous Improvement: To maintain a balance between productivity and safety.
- ▶ **Standards and Compliance:** Compliance to standards like ISO 10218 (for Cobot) ensures consistent in safety practices across different scenarios.



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So, why Risk Assessment? First of all, why is it so important to have Risk Assessment for a collaborative robot environment?

Why Risk Assessment?

For collaborative robot environment



- ▶ Safety: Cobots work along side humans, and ensuring their safe interaction is paramount.



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First of all, collaborative robots work alongside humans. So, ensuring their safe interaction is paramount because robots and humans have overlapping workspaces and are in very close collaboration. They touch each other; they handle each other, right? So, it can hit the Humans anytime, so in that case, you have to access the spaces, you have to

access the surroundings, you have to access the power and force-limiting thing. Everything that is related to safe interaction, so safety is very, very important.

Lecture 03: The Process of Risk Assessment

Why Risk Assessment?

For collaborative robot environment

- ▶ Safety: Cobots work along side humans, and ensuring their safe interaction is paramount.
- ▶ Collision avoidance: Cobots move within shared workspaces.



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Next comes collision avoidance. The Cobot moves within a shared workspace, so that is the reason collision is quite probable. So, how much force can a robot put on a human, right? How much force does a human require to handle a robot? So, all these parameters we need to study. So, risk assessment allows us to access those parameters and parameters for collision avoidance. So, that is what is to be assessed as well.

Why Risk Assessment?

For collaborative robot environment



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- ▶ Collision avoidance: Cobots move within shared workspaces.
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Task complexity: As the task becomes complex, you need more and more interaction. Things like for a pellet pickup, let's say it has to be picked up from a place and placed it down somewhere, so it is two tasks which are there: picking up and placing it. Let us say if the task goes a little more complex, let us say you have to insert a pellet inside a hole. So, in that case, it picks up, it inserts it, it releases it, and it picks up the other one, or it places it somewhere. So, the task becomes a little more complex. So, as the task goes more and more complex, the interaction between the human and the robot becomes more and more. So, risk assessment helps us to determine appropriate safety protocols which are to be followed for each subtask, right? So, task complexity is very, very important, right?

Cobot design risk assessment helps us to determine the Cobot, right? Which Cobot do we have to put in use, and how a particular Cobot is to be designed? This is at both ends. One is for the manufacturer, and the other is for the integrator, maybe the developer or researcher, right? It helps us to determine the reach, payload capacity, joint flexibility, or end-effector compliance that you are looking for in a particular application, right? So, that is why risk assessment helps us to determine each of these parameters, which are very important.

So, next comes Human-Cobot Interaction or Human-Robot Interaction. In this case, it is a Cobot. So, considering factors like proximity, how close a human is going to be in the workspace of the robot, and what interaction forces will coexist between the robot and human. Speed during the collaborative task, how fast this task is going to be executed; it can be quasi-static, and sometimes the contact could be transient, so you never know. So, is there any probability of having such transient contacts as well? So, all those things we need to determine beforehand. So, risk assessment, I tell you, is done at least twice: once during the implementation of any task assigned to the robot, and second, if there is any incident that has happened. So, risk assessment also helps us to evaluate the protocols which have been violated. So, that is why it is very important. It helps us to decide on the safety measures and the training that we need to provide to the operators. Right.

Work area analysis: Optimisation of the layout, and lighting that should exist because humans need sufficient light in order to see the things around. Robots may use some other kinds of sensors also, but humans rely mostly on vision. So, any obstruction ensures safe operation. So, any obstructions need to be analysed. So, the whole work area needs to be analysed.

Why Risk Assessment?

For collaborative robot environment

- ▶ Safety: Cobots v
- ▶ Collision avoidar
- ▶ Task complexity
- ▶ Cobot design: H
- ▶ Human-Cobot Ir during collabora
- ▶ Work Area Anal operation.
- ▶ End-of-Arm Tooling: Assessing the attached tools ensures the safety of humans a



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End of Arm Tooling: commonly known as EOAT. Assessing the attached tool ensures the safety of humans around. So, the end of the arm tool may have some surfaces to hold the

object that it is handling, right? So, if that surface goes wrong, your object may fly away while it is transporting from one place to another. So, if at all you have not done any risk assessment or any estimation of those surfaces, right, textures and all, how do you know? So that is why end of arm tooling, whether that arm has already finished its life, you never know. So, those things need to be assessed also.

Continuous improvement: risk assessment helps us to do continuous improvement. It is not at the time of implementation of any task that is given to the robot or at the time of the incident it is done. It is a continuous improvement task. Sometimes it is done immediately, like in the case of a planned maintenance system or some kind of regular interval where they do some kind of checks. So, that is why it is very important to see continuous improvement to maintain the balance between productivity as well as safety. So, both should be in the paramount, right? So, you cannot lose productivity in the name of risk assessment or something. If it is necessary, we'll do it. If it is not, we can simply skip it for the next time. OK, or there may be some preliminary checks that are done before every start of the robot.

So, there may be a starting procedure, a stopping procedure that goes on every day. It's a continuous task, but sometimes, it is done at the start when the task is assigned to the robot. Not every day, and few tasks are done at the end may be when you are decommissioning the robot for a different task, or maybe or maybe after some kind of incident that has happened. So, yes, continuous improvement is very much required and for compliance with various safety standards, right? So, you have learned about various ISO standards that apply to the Cobots. So, yes, basically, Compliance with standards like ISO 10218, which is especially for Cobots, is very important here. It ensures consistency in safety practices across different scenarios. So, we will look at ISO 10218 in very much detail because that is the one that actually goes into doing the risk assessment task apart from the ones that we have discussed in the previous lecture.

Risk assessment and avoidance: Using ANSI/RIA TR R15.306-2016

Robotic Industries Association (RIA): U.S. National Adoption of ISO 10218-1,2:2011



Countries	Robot Manufacturer/ Integrator
International	ISO 10218-1,2
Canada	CAN/CSA-Z434-14
China	GB 11291.1-2011, GB 112891.2-2013
Denmark	DS/EN ISO 10218-1,2
European	EN ISO 10218-1,2
Germany	DIN EN ISO 10218-1,2
Japan	JIS 8433-1,2
South Korea	KS B ISO 10218-1,2
Taiwan	CNS 14490-1 B8013-1,2
United Kingdom	BS EN ISO 10218-1,2
Brazil	ABNT NBR ISO 10218-1,2
USA	ANSI/RIA R15.06

*These standards are updated after cyclic review process.

▶ Hazard identification and risk assessment

▶ Design requirements and protective measures

▶ Actuating controls

▶ Safety-related control system performance

▶ Robot stopping functions, Speed control

▶ Operating modes, Pendant controls

▶ Control of simultaneous systems

▶ Collaborative operation requirements

▶ Singularity protection

▶ Axis limiting, Movement without drive power

▶ Provisions for lifting, Electrical connectors

What is Risk assessment and avoidance? It is normally done using various standards, various similar standards which exist across different nations. It is the adoption of ISO 10218-1 and 2. Again, 2011 is the year when it came in, and then it is revised after every five years or maybe in between also, that depends. So, these standards are updated after every cyclic review process, right? So, you should not just take any standard as such, right? So, yes, the risk assessment standard, that is ISO 10218, is adapted across various nations internationally. In India also, we follow this one. The base guidelines which are there in ISO 10218-1 and 2. 1 is for the manufacturer, and two is for the integrator. In Canada, it has some other name. So, the same adaptation has gone in there also. In China, it is there. Denmark, Europe, Germany, Japan, South Korea, Taiwan, the UK, Brazil, and the US.

So, basically, I will discuss today's ANSI/RIA R15.06; that is what it has so many other things apart from hazard identification and risk assessment. It also has chapters on design requirements and protective measures for the Cobots. Actuating controls, what goes into actuating, what all controls it should provide, if at all it is a safety-related control system performance. Apart from a standard control system, it also has dedicated safety-related control functions. So, what should be the isolating workspace may be, or can it be a Cartesian workspace that can be auto-isolated? There may be joint limits in the software

and other such things. So, safety-related control system performance is also evaluated here. Robot stopping functions, in what scenarios should the robot stop, and what functions should this robot manufacturer offer to any programmer?

Speed controls, operating modes, and pendant controls, what all emergencies should be there on the Teach pendant of the robot that is primarily used to teach a robot, maybe an emergency stop it is talking about, or maybe three-position switches which are there at the back of your teach pendant, sometimes in the front also. Like control of the simultaneous system, how many numbers of IOs or how many numbers of simultaneous, let us say if it is a turntable, it is a linear rail, it may be a conveyor. So, how many such simultaneous systems that can go along the Cobot operation, which is also discussed in this? Collaborative operations requirement, the pressure limits, force limits. So, those things. Singularity protection. This is very, very important. What would happen in case the robot goes to a singularity?

In the case of regular programming, you always take care while programming only, but in the case of a Cobot, even due to some external forces, the robot may enter into a singularity zone. So, if at all it goes into a singularity, what should be the behaviour of your robot? So, those things are explicitly discussed in the case of Cobots.

Axis limiting and movement without drive power. So, if there is any power failure, what would happen to the joints? Whether the Brakes will be applied or the robot will go safely to the home position using its backup power or something. So, those things are discussed here. Provisions for lifting, electrical connections, what safety is, what the standard of wiring should be that is used. So, all those things are discussed here. So, we will focus on hazard identification and risk assessment only next. So, let us begin with that.

Prerequisites of Risk Assessment



- ▶ Create team: Operators, Technicians, Managers, Specialists, Insurance, Stake holders.
- ▶ Identify the Cobot/Integrated systems operating process
- ▶ Collect information: Limits, interlocks, safeties, life-cycle, design, specifications, wiring, any safety bypass, energy sources, accident/maintenance history, training, PPE, etc.
- ▶ Procedures for the robot installation, maintenance, and usage.
- ▶ Manufacturer's recommendations for maintenance, special/standard tools, spares and operating procedures. Any local or industry standard procedures.
- ▶ Identifying the Hazardous areas: Edges, EOAT, Part. Follow Sub-Task/Hazard approach
- ▶ Assumptions: Machine is practically safe! No fencing is required, Working on PFL. All safeguards in place, Zero Risk! - Only tolerable risk is achieved, etc.
- ▶ Identify the risk level and the required level of risk reduction.
- ▶ Shut down and Sign-off.



*One can design their own process based on the best practices in the industry



So, the Prerequisite for Risk Assessment goes on like this. So, the first thing before risk assessment is that we need to Create a team. So, the team may comprise operators who are actually operating the robot, technicians who maintain it, and who program it, right? Managers on the shop floor there may be multiple systems which are there. The manager may take care of all those so that he may be involved. Any specialist, if there is one, maybe a Cobot specialist, an insurance guy like stakeholders. all the stakeholders who are responsible for running and operating this Cobot may be part of the team. So, while assessing the risk of a system, not just a Cobot, a team may be formed that has all these. Okay, they identify the Cobot/Integrated system operating process. You need to identify the process where things can go wrong, right? So, those things are to be identified first. In the case of Cobots, it is a Cobot, and there are many other integrated systems. It may be a turntable, a linear rail, or a conveyor. So, the whole system is to be identified for which risk is to be assessed.

Next, collect information like what are the limits here? What are the safety locks? In the case of industrial robots, it can be a door. If it is open, the robot will not start, right? So, if it is an emergency stop, a switch is pressed somewhere. So, it need not start, right? So, there are many other such interlocks, mechanical and electrical, which do not allow the robot to operate until and unless those interlocks are freed upon. There are many other

safety features. What is the life cycle? Let us say if it is a tool that is at the end, the life cycle of the tool is to be checked. Design of the Cobot—which particular design? Is it suitable for this particular application or not? Specifications—what is the repeatability? How much is the compliance that is possible with this kind of setup? Right.

Wiring— any safety bypass. This normally should not be done. It is never to be done. But if at all a post-assessment finds this, it is to be identified as well and marked. OK. Energy sources—where is the energy coming from? Is there any emergency source existing or not? Accidents or maintenance history. The history of the Cobot is to be studied before we do any assessment on it. If any major overhaul and any of the access was done, it is to be taken care of. Training— if it is provided to the operator, personal protective equipment, what are all the equipment required so all those things need to be covered here. Procedures for robot installation, maintenance, and usage should be clearly followed while doing the installation. Before doing any maintenance, one should read that and follow the proper maintenance procedures, and also while it is in operation. Any manufacturer's recommendation for these tasks as well. For maintenance, Special or standard tools that should be used to do maintenance. Spares, proper spares should be there. Third-party spares are not prescribed. Any operating procedure to do such maintenance. Any local or industry standard procedures should also be considered. Not just the manufacturer's recommendation. Every industry scenario may be different. So, depending on that, those precautions should also be noted down.

Identifying the hazardous areas like any edges, sharp edges, sharp surfaces, rough surfaces, kind of surfaces, end of arm tooling, and part. Follow the sub-task hazard approach. For every sub-task, you have to split the whole task performed by the robot. The whole task is to be split into multiple small sub-tasks. Each subtask can have its own hazard. So, you have to split them all and then identify the hazardous area before you proceed.

Assumptions: there are a few warnings on that. The machine is practically safe. This is an assumption, and it is 100% wrong. No fencing is required. So, it is never the case for a Cobot. It may depend on the application, but the robot may require fencing as well, even if it is a Cobot working with pressure force limiting. So, this is again an assumption, and

it is 100% limited, so nothing will happen to an operator. So, these are a few assumptions. All safeguards are in place. You have to remove all the safeguards while doing any assessment. You have to think as if they are not there; anything can go wrong. Even the safeguards can go wrong. So, all evaluations should be done with the safeguards not in place. So, you cannot assume that they are there. So, nothing is going to happen.

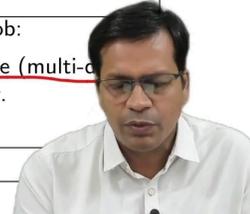
Zero risk is a myth. There is nothing called zero risk. Only tolerable risk is achieved. So, the machine is never practically safe. You got it. So, these are some of the assumptions, and they may or may not be considered.

So, identify the risk level and the required risk. For risk reduction. So, what are all the things that should be done in order to make it a safe robot, right? So, you have to identify all the risk levels and the appropriate risk reduction procedures, right? First shutdown, post-accident, you have to shut down and sign it off. People are doing some inspection; you have to flag it off, Even during maintenance, you have to do this, even while installing and doing the inspection post-accident. So, this is a regular procedure; you have to shut down and sign off before any operation that is done on a robot or even a Cobot, okay? So, this is an industry best practice, but one can design their own process based on the best practices in the industry. So, these are some of the prerequisites before we start.

RIA TR R15.306-2016 Table 1: Injury severity factor



Injury Severity (S)	Serious S3	Normally <u>non-reversible</u> : likely will not return to the same job after recovery from the incident: <ul style="list-style-type: none">▶ May result in any of these: <u>fatality, limb amputation, long-term disability, chronic illness.</u>
	Moderate S2	Normally <u>reversible</u> : likely will return to the same job after recovery from the incident: <ul style="list-style-type: none">▶ May result in: <u>broken bones, severe laceration, short hospitalization, short-term disability, loss time (multi-day), fingertip amputation (not thumb)</u>
	Minor S1	<u>First aid</u> : no recovery required before returning to job: <ul style="list-style-type: none">▶ May result in: <u>bruising, small cuts, no loss time (multi-day)</u> does not require attention by a medical doctor.



So, how is it actually done? So, as per ANSI/RIA TR R15.306-2016, this is the standard table 1 that is there in the standard injury severity factor. As a letter is there for this. So, based on injury severity, it may be classified as serious, moderate, or minor. So, serious could normally be non-reversible. In this case, the person, the operator is likely not to return to the same job after recovery from the incident. It may be the result of any of these, like fatality, limb amputation, long-term disability, chronic illness, or something like that. In the case of moderate, it is a reversible thing. The operator comes back to the job after recovery, and it may be a broken bone or laceration that has happened, like short hospitalisation, short disability, those kinds of things, right? Or even sometimes fingertip amputation, not the thumb, is considered as moderate.

Minor (S1) is first aid. With first aid, normally, he comes back to the job. It may result in bruising, small cuts, no loss of time, multiple days, and does not require attention by a medical doctor. So, based on injury severity, it may be classified as S3, that is serious, moderate S2, minor S1, right?

RIA TR R15.306-2016 Table 1: Exposure factor



Exposure (E)	High E2	If any of the following are applicable, the rating is HIGH <ul style="list-style-type: none">▶ Typically more than once per hour▶ Frequent or multiple short-duration▶ Durations/situations that could lead to task creep and do not include teach
	Low E1	If either of the following is applicable, the rating is LOW <ul style="list-style-type: none">▶ Typically less than or once per day or shift▶ Occasional short durations



Next is the exposure factor, the exposure factor. How much you are exposed, the exposure factor. It may be high, it may be low. So, if any of the following are applicable, it is rated as high. Typically, more than once per hour, if the person and robot are interacting more than once per hour, frequent or multiple short-time interactions, and short-duration interactions. Duration situations that could lead to task creep or do not include, this does not include a teaching process, teaching people to get involved for a longer duration. So, all these are considered as high exposure, right? A low exposure could be either of these, typically less than once per day or a shift, right? Occasional short duration is okay. So, this is considered as low exposure, right?

RIA TR R15.306-2016 Table 1: Avoidance factor

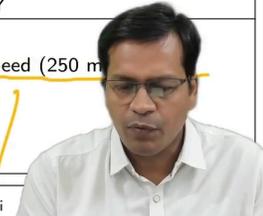


Avoidance (A)	Not possible A3	<ul style="list-style-type: none"> ▶ Insufficient clearance to move out; Safety-rated reduced speed control is not used ▶ Robot system layout causes the operator to be trapped, with the escape route toward the hazard ▶ Safeguarding is not expected to offer protection from the process hazard (e.g. explosion hazard) <p>If any of the above are applicable, the rating is NOT POSSIBLE</p>
	Not Likely A2	<ul style="list-style-type: none"> ▶ Insufficient clearance to move out; Safety-rated reduced speed control is used ▶ Obstructed path to move to a safe area ▶ Hazard is moving faster than reduced speed (250 mm/sec) ▶ Inadequate warning/reaction time ▶ Might not perceive the hazard exists <p>If any of the above are applicable, the rating is NOT LIKELY</p>
	Likely A1	<ul style="list-style-type: none"> ▶ Sufficient clearance to move out of the way ▶ Hazard is incapable of moving greater than reduced speed (250 mm/sec) ▶ Adequate warning/reaction time ▶ Positioned in a safe location away from the hazard <p>If any of the above are applicable, the rating is LIKELY</p>

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Next is the Avoidance Factor. Can it be avoided, right? Avoidance factor, so not possible, not likely, and likely to be avoided. So, these are a few points in that, like insufficient clearance to move out. Right. So, an accident cannot be avoided. Right. If at all things happen, it does happen. You have no way to go out. Safety-related reduced speed control is not used. It is not used. Robot system layout causes the operator to be trapped with the escape route towards the hazard only. He cannot escape. Safeguarding is not expected to offer protection from process hazards. For example, an explosion hazard. So, in any of these, it is considered that avoidance is not possible. And this is dangerous, you see.

The next one is not likely. Insufficient clearance to move out. Safety-related reduced speed is used over here; it was not used over here, it is used. An obstructed path to move to a safe area. The path is there, but it is obstructed. The hazard is moving faster than the reduced speed, and this is also defined as 250 mm per second. Inadequate warning and reaction time might not perceive that the hazard exists. So, the end-user may not see that the hazard is there. So, that could be the case. So, in all these cases, it is not likely, and the last one is very likely that it can be avoided. So, sufficient clearance to move out is there. The hazard is incapable of moving at greater than the reduced speed of 250 mm per second. Adequate warning and time are there. Positioned in a safe location away from the hazard. So, in this case, it is likely to be avoided.

RIA TR R15.306-2016 Table 2: Risk level decision matrix (SEA)



Severity of Injury	Exposure to the Hazard	Avoidance of the Hazard	Risk Level
S1 – Minor	E0 – Prevented	A1 – Likely	NEGLIGIBLE
	E1 – Low	A2/A3 – Not likely/possible	
	E2 – High		LOW
S2 – Moderate	E0 – Prevented		MEDIUM
	E1 – Low	A1 – Likely	HIGH
	E2 – High	A2/A3 – Not likely/possible	
S3 – Serious	E0 – Prevented		LOW
	E1 – Low		HIGH
	E2 – High	A1/A2 – Likely/Not likely	
		A3 – Not possible	VERY HIGH



So, based on SEA analysis, S for injury severity, E for exposure, and A for avoidance, right? So, you classify the kind of risk level. So, this is the risk level classification, whether it is very high or negligible, depending on this. So, based on the above S, E, and A categories, see if it is S1 and E0, E0 is totally prevented; it directly goes to the negligible. But if it is E1 and A1, it is likely, so again, it is negligible. So, accordingly. So, if it is S2 and if it is E0, it is still prevented, and it goes to low. But if it goes to S2 moderate and E2 high and A2 or A3 not likely and possible, it goes to high. You see, depending on different combinations, it reaches negligible or very high-risk factors. So, very high risk level. So, depending on the various combinations of severity, exposure, and avoidance, risk levels are determined, as shown in Table 2 of this standard.

Sample Risk Assessment Data Template



Sequence No.	Task Description	Hazards	Prior to safeguard				Solution	Validation			
			Severity	Exposure	Avoidance	Risk Category		Exposure	Avoidance	Severity	Risk Category
	Kooy	—	S2	E1	A2	High	←	E2	A1	S1	Low



So, now, how do we perform a risk assessment for a given job? So, this is a sample table that I have shown here. It is also there in the standard. So, the sequence number for the task description comes here. For example, I will tell you. So, let us say this task could be a general housekeeping task to observe. The person, this is a housekeeping task. The hazard could be - He may fall from a height; he may be climbing up a ladder and may fall. In that case, the severity may be S2, E1 may be the exposure level, and A2 could be the avoidance level. Accordingly, it may result in S2, E1, and A2. Let us go back and see S2, E1, and A2. You see, the risk level is high, as shown here. So, it falls into the high-risk level category. So, again, the solution is recommended by the risk assessor. He may suggest using a platform or a taller ladder to perform this task. That is the recommended solution provided. Once the solution is implemented, you perform the risk assessment again. In this case, it may have some. So, in this case, it may be E2, which has come down from E1 to E2. Avoidance has become A1; it is now totally avoidable. The severity has also reduced from S2 to S1, and the new risk category is S1, E2, and A1. So, you see now S1, E2, and you see it is A1. But if it is E2, it is a low category. So, it goes to low, you see.

So, then you see that for every such task, you create such a table, and there are some recommendations and solutions that are recommended. After implementation, you go back and do the validation that makes the table complete.

Risk Reduction Measures



Based on the Risk Level category, one or a combination of the following are required as means to reduce the risk to acceptable levels. The **validation** is performed after the recommended solution is implemented.

- ▶ **Elimination/substitution of the hazard:** Severity, Frequency, and Avoidability
- ▶ **Engineering controls:** Interlocks, light curtains, limit switches, barriers, etc.
 - *Passive:* Limiting moving masses/inertia, Rounded edges, Soft surfaces, Natural compliance, Padding.
 - *Active:* Limiting forces/torques, Velocities/Momentum, Virtual Limits, Joint or End-effector Compliance.
- ▶ **Safety awareness:** Light signals, Signs, Posters, Bleepers, Computer Warnings, etc.
- ▶ Training and Safety/Inspection/Operating/Maintenance Procedures
- ▶ **Personal Protective Equipment (PPE)** 

*The first two points deal with engineering while the others are administrative procedures



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Once this is formed, then you do the Risk Reduction Measures. Some measures could be like this. Based on the risk level category, one or a combination of the following are required as a means to reduce the risk to acceptable levels. The validation, as you have seen, is performed after the recommended solution is implemented. So, it may include the elimination or substitution of the hazard. That gives you a new severity level. Frequency may be reduced. It may become avoidable now.

Engineering controls like interlocks can be put in place. Safety curtains can be put in place. Limit switches and barriers can be put in place. Engineering controls can be of two kinds. It can be passive. It can be active. Passive controls could be limiting the moving masses and inertia. You are reducing the inertia of the system. Maybe the object, maybe the robot. Right or accessories, rounded edges, soft surfaces, you try to use them. Natural compliance: how much should be the natural compliance of the system? Padding, if it is possible, you fit it. Active compliance or active engineering controls limit the forces and torques that are done by the robot programming that is normally present in any Cobot, velocity or momentum reduction. Virtual limits: even when there are physical limits,

there may be some virtual limits at the software end that further limit it to certain levels. Joint or end-effector compliance: how much is required for this particular task? So, they can be put. So, active and passive. There are two types of engineering controls.

Next comes Administrative control, which is safety awareness. You have to make the people aware; the operator is aware of these things by putting light signals, signs, posters, and beepers. Computer warnings: If all your robot is controlled by some kind of HMI, Human-Machine Interface, it can pop up with an error showing that this operation would cause these errors or these warnings. They exist for this particular task. So, it is actually warning the operator first, that is, that could be there as well.

Next comes proper training and safeties. Inspection, operating, and maintenance procedures are to be followed correctly. The final one is personal protective equipment. Proper gloves should be worn. If required, eye goggles are to be used. Those PPE gadgets should be in place. So, you see the first two points dealt mostly with engineering, while the others are administrative procedures. So, they are handled in a different way. So, this is how risk can be reduced. So, ultimately, you follow the complete procedure, and finally, the risk is assessed and then finally reduced.

So, that is all for this lecture. In the next lecture, we will see how Force Control, which serves as a primary technology behind any Cobots, has evolved. Technology Transition: we will see how the technology has transitioned over the years and what it is now. The fundamental Technological Difference between an industrial robot and a Cobot is what we will see. Cobot hardware changes what was done in terms of its arm, its controller, and the overall system. So, all these we will be discussing in the next class. So, that is all for this lecture.

Thanks a lot.