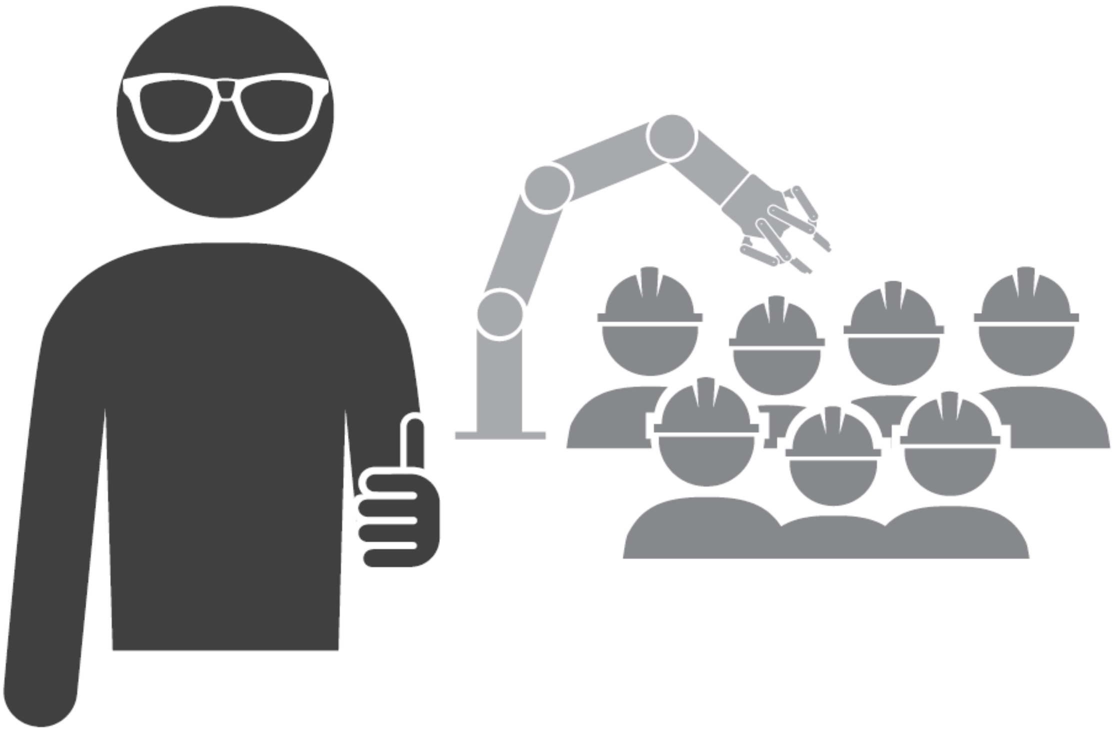
HOW TO PERFORM A RISK ASSESSMENT FOR COLLABORATIVE ROBOTS



LEAN ROBOTICS

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Revision: 1.0

Lean Robotics: Simplify Robot Cell Deployments

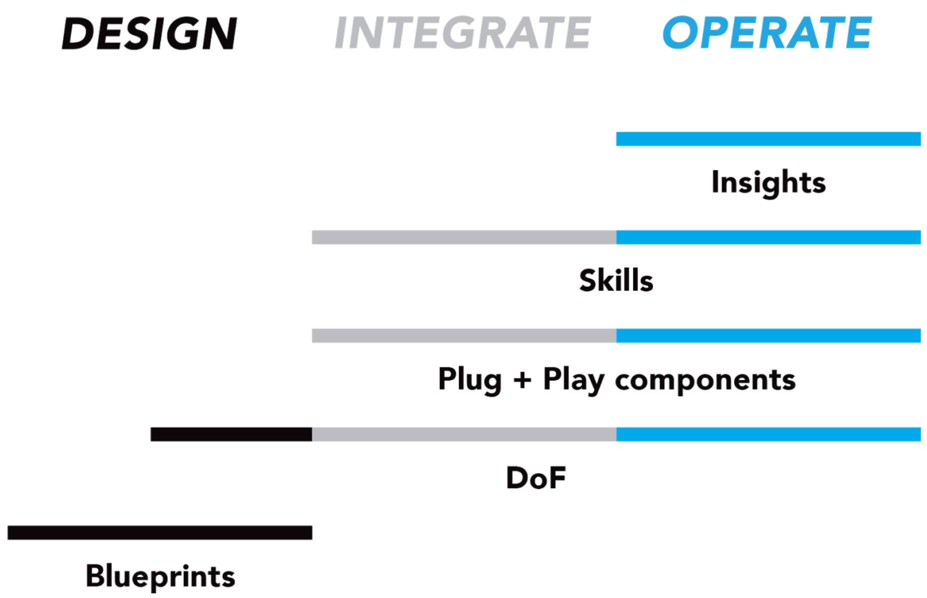
Whenever you ask if robots could work in your factory, the answer you receive is always a hesitant "It depends." It depends on your factory, your team, which robot you choose, what you want it to do… and a whole lot more.

If you're a first-time robot user, how can you get started? How do you get from your initial idea to a productive, working robot? And if you've already got a few robotic deployments under your belt, how can you scale up your robotics efforts throughout your factory—or across multiple factories?

The answers can be found in **lean robotics: a methodology for simplifying robotic cell deployments**.

Lean robotics is a systematic way to complete the robotic cell deployment cycle, from design to integration and operation. It will empower your team to deploy robots quicker and more efficiently than ever before.

Lean robotics divides robotic cell deployments into three phases: Design, Integrate and Operate.



Robotiq's library of eBooks covers the different phases of the robot cell deployment to ensure that you have access to tips from robotics experts all along.

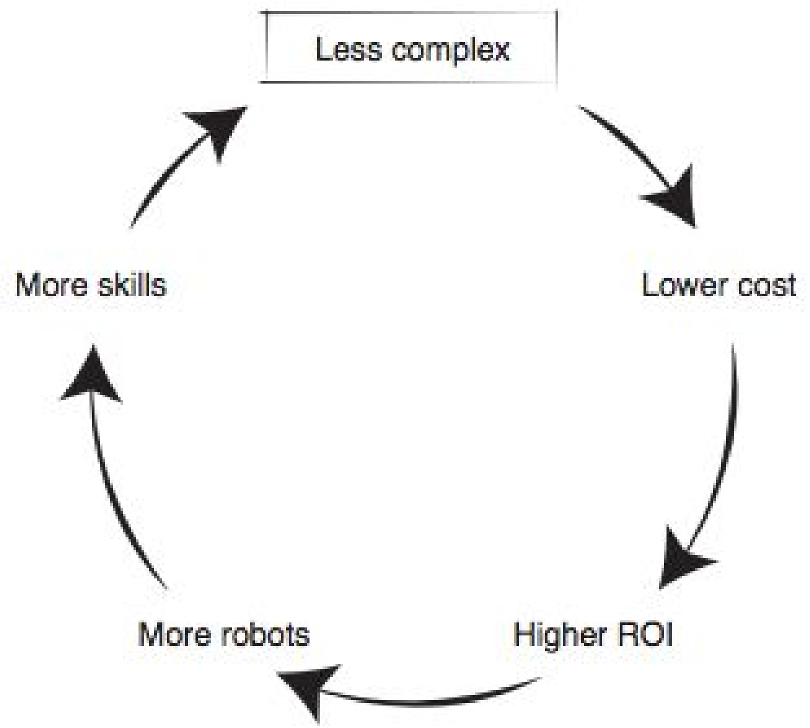
Learn more about Lean Robotics on **leanrobotics.org**.

This Ebook Covers the Operate Phase

The operate phase represents the end goal of deployment: having a productive robotic cell that does its job properly on an ongoing basis.

OPERATE

When you're in the operate phase, your robotic cell is finally producing valuable parts for your company, and all your hard work will start to pay off. Since the operate phase is a continuous loop, there are many tips to optimize your robot cell and planning for the next one.



INTRODUCTION

With the introduction of collaborative robots in industrial markets, the field of robotic safety has been shaken up. Now that robots can feel their surroundings and with the, removal of safety fencing and other safety monitoring devices, collaborative robots are creating a revolution not only in the manufacturing world, but also in the safety requirements related to using robots.

Now that this type of robot is gaining in popularity, it is doubly important that safety requirements are evaluated to make sure human-robot collaboration is done correctly. Since initial ISO standards were adapted for industrial robots, these standards did not take into account the specificities of collaborative robots. In January 2016, the ISO committee launched the *ISO/TS 15066 Robots and Robotic Devices - Collaborative Robots*. This technical specification is uniquely focused on collaborative robotic applications and presents guidelines for different speed, force and pressure measurements that are allowable during direct human robot collaboration. Since this is a technical specification, there is no regulatory requirement to comply with this specification for either manufacturers or integrators at the moment. However, since this tech spec seems to make sense for the robotic industry, we expect to see it become an official standard in a relatively small amount of time. Why not start integrating cells that comply with ISO/TS 15066 right away?

This is precisely what this document is about. We aim to give you information on how to do a risk assessment for a collaborative robot. The process will be developed and explained in detail and a couple of examples will be given to help you figure how to complete a risk assessment yourself.

This is important: We are not a risk assessment firm and information in this eBook is only provided as a guide and to initiate discussion. For more relevant information specific to your particular situation you should contact your local robot integrator, who can determine which regulations should apply to you for proper risk assessment for your application.

SCOPE

The main focus of this eBook is to help you understand the risk assessment process and to give you the necessary tools to achieve a proper risk assessment for collaborative robots.

When most people talk about ‘collaborative robots’ or cobots, they mean what ISO/TS 15066 calls power and force limited robots. While these types of robots are becoming more popular and are marketed as being safe, this does not automatically mitigate the safety concerns that come with the introduction of these robots in a workshop. With this eBook, we want to give you the tools to help you develop an internal knowledge of risk assessments in relation to force limited robots, so that you feel more at ease when introducing them to your workshop.

With the introduction of the technical specification ISO/TS 15066, a lot of data, calculations and methodologies were developed to make sure your collaborative robot application is safe for use alongside humans. However, the technical specification does not directly affect the use or the purpose of the robot and its application. This is why robot manufacturers will still use third parties to accredit their robots. This means that according to some designated external safety body, under certain given conditions, the robot is certified as being safe as a tool. This does **NOT** means that the application will automatically be safe. So, this means that the application in its entirety requires a risk assessment. This is why you should build internal knowledge in terms of safety, so you can use your past experiences to build a new risk assessment for any given situation.

This eBook will be split into several sections that will describe the different parts of the risk assessment process. Each section will explain how this part of the process could be done and the text boxes represents examples of a virtual risk assessment. All the information in these examples should be considered realistic but not precisely accurate. We do not certify that the different calculations and estimates can be used in production. They are for descriptive purposes only.

1. Document Identification

The document identification section is where you certify that the risk assessment is valid, up to date and verified. It is a bit like the cartridge in a technical drawing: A place where the name, number and revision are present and where the people involved in the process sign to certify the validity of the document. Here's an example of what should be found in the document identification and revision part of the risk assessment.

Document Identification			
Project Name	*UR-ROBOTIQ-MACHINETENDING-001*	**Project No.**	*UR-RB-MCH-001*
Version	*0*	**Date**	*04/11/2016*

	Name	Signature	Date
Lead Author	*Salvador Gomez*	*X*	*04/11/2016*
Reviewed by	*John Butler*	*X*	*04/11/2016*

Revision	Description	Changed by	Date
A	*Initial Draft*	*S. Gomez*	*04/11/2016*

Figure 1: Example of Document Identification and Revision Grid.

It is really important to list the modifications and iterate the revisions in order to keep track of the changes that have been made to the cell. In fact, a modification in the functionality of the cell can make a big difference in the risk associated with the use of the cell. Keeping track of these modifications makes understanding the risk assessment a lot easier.

2 Robotic Cell - General Information

This section will provide information about who, what, why and how. In other words, who is doing the certification, what process is involved in your collaborative robot cell, why you decided to do a risk assessment and more precisely which process or how you will perform the risk assessment. It's pretty much an introduction to the risk assessment document.

The risk assessment example could serve as a template.

2.1 Project Information

In this section you should describe what type of machine/robot/device/gripper you will be using in your collaborative robot cell. Having all the different information and serial numbers in one place can be useful in case of accident, but also when you need to call for support or maintenance for your robotic cell.

MACHINE INFORMATION	
Machine Name:	UR5 DEMO CELL
Manufacturer:	UNIVERSAL ROBOTS
Machine Type:	Industrial Robot
Seriel Number:	XXXXXXXXXX
Date of Manufacture:	MM-DD-YYYY
Machine Certification:	[CE or other certification]

DEVICE INFORMATION	
Device Name:	Robotiq 2-Finger 85 Adaptive Gripper
Manufacturer:	Robotiq
Device Type:	Robotic Gripper
Seriel Number:	XXXXXXXXXX
Date of Manufacture:	MM-DD-YYYY
Device Certification:	[CE or other certification]

ASSESSMENT PERSONNEL / ASSESSMENT DATE			
Initial Risk Assessment			
Lead Author:	Salvador Gomez	**Date:**	04/11/2016

CUSTOMER PERSONNEL			
Name:	Mario Turgeon	**Function/ Job Title:**	Aut. Engineer

Figure 2: Example of Machine and Device Information

2.2 Motivation

The motivation section of the risk assessment is reserved to explain why you are doing a risk assessment. You need to specify which standard you will be using to perform your risk assessment process.

Robotiq Inc. wants to develop a risk assessment guide for collaborative robots users. For this reason, Robotiq Inc. took information in a Pilz© documentation format to conduct a formal risk assessment on their UR5 demo cell . The cell is a force limited collaborative cell.

This risk assessment complies with the [enumerate applicable standards]. In addition, the collaborative cell aspects were assessed following the guidlines of the ISO. More particulary using the guidelines by the ISO/TS 15066 for the case of the Robotiq 2-Finger 85 Adaptive Gripper.

The construction, safeguarding, and risk sources were evaluated for compliance with applicable standards listed in this report.

This Risk Assessment has been carried out on 11 April 2016.

Figure 3: Example of Risk Assessment Motivation

2.3 Method of Risk Reduction

Since the risk assessment is very procedural and a lot of different techniques exist to achieve this process; we recommend explaining what procedure you intend to use. As most of the risk reduction processes are similar, you should strive to make things clear and demonstrate your methodology. Here's an example.

In accordance with ISO 12100, the risk assessment is implemented in a series of logical steps to enable a systematic examination of the hazards associated with machinery. Risk assessment is followed, whenever necessary by risk reduction as described in clause 6 of ISO 12100: 2010. When this process is repeated it gives an iterative process for eliminating hazards as far as possible and for implementing safety measures.

The risk assessment methodology approach includes:
-- **Risk analysis**
- o Determination of limits
- o Hazard identification
- o Risk estimation

-- **Risk evaluation**

The risk assessment provides the information required for the risk evaluation, which in turn allows judgements to be made on the safety of machinery.

The *Diagram 1* shows the step-by-step process of risk analysis:

Figure 4: Example of Risk Reduction Method

To synthesize all of this is pretty straightforward. You first need to determine the robot limits or what the robot will be used for (Determine the system's scope). See section 3.1, 3.2 and 3.3 for more details.

After that, all potential risks (basically all work operations) have to be monitored. What you really need to do here is to separate all the robot's motions and actions into potential risks. When a potential interaction can occur between a human and the robot cell, note this potential interaction.

Estimate the risk by using the technique described in section *3.4 Risk Estimation & Evaluation Criteria.*

Once all the risks are rated you can rank them in the order from the most dangerous to least dangerous. After that, evaluate each risk and determine if it is acceptable for the application or not. If the risk is acceptable, you are done with this risk. If not, you need to integrate safety measures or change something in your collaborative robot application to make it safer.

Once the modification has been made, you need to restart the risk assessment process all over again in order to insure that the modification did not make the cell more dangerous.

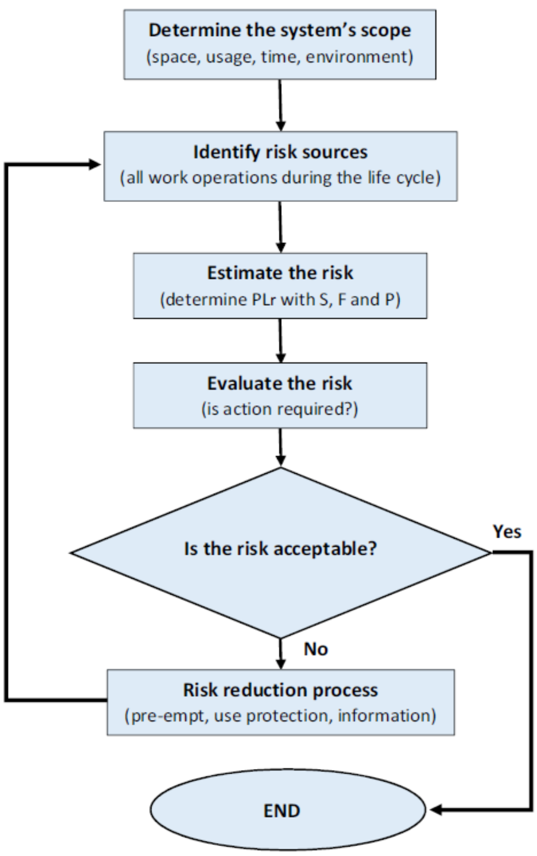


Diagram 1: Risk Reduction Process

2.4 Limits of the Report

As you probably understand there are certain limits to doing a risk assessment. In fact, you probably cannot go through every single safety aspect in fine detail. You need to be able to trust robot and device manufacturers for the safety of their product and be able to rely on the results they provide for their product. That being said, you need to prove that you reviewed their documentation before relying on them. This part of the risk assessment is dedicated to listing the robot and device specifications and documentation.

Again you can refer to the risk assessment example as a template.

This risk assessment report is based on information that was accumulated during the on-site risk assessment of the [name of the cell] at [company name] on the [date].

This risk assessment for work equipment examines significant hazards where risk reduction measures still need to be applied.

The information was accumulated in the following fashion:
1. Discussions with [name of the departement] personnel
2. Reviewing all available machine technical information
3. Conducting a physical examination of the machine

In order to ensure the accuracy of the risk assessment for the machine, it is imperative that the information provided on the date of the risk assessment be correct and reliable. [name of risk assessment personnel] cannot take any responsibility for judgements made on inaccurate or lack of information.

The following technical information was made available for the [name of the cell]:

DOCUMENTATION EXAMINED			
No.	Document Name	Type	Issue Date
XXXX	Universal Robots for UR5 User Manual	Operating Manual	Month/ Year
XXXX	Robotiq FT-300 User Manual	Operating Manual	Month/ Year
XXXX	Robotiq 2-Finger 85 User Manual	Operating Manual	Month/ Year

Figure 5: Example of Documentation Examination

3. Machine Assessment

This part of the process will provide all the required information about the robotic cell, the potential hazards and how to solve them. Notice that the different images, description, diagrams, figures and other content in this risk assessment eBook can only be used as an example and not as a substitute for a real risk assessment process.

3.1 Basic Machine Description

This is where you describe what the 'machine' or robotic cell in this case is used for.

UR5 picks up a part from a table. The Gripper seeks, in closed postion, for a part and when a threshold of 10 N is reached, the robot interprets this as part located at this position.

When the part is identified, the robot descends with fingers opened and grabs the part on both sides. The robot is simply used for demonstration so no second operation is programmed. The part is elevated 0.5 meter.

The robot decends in the Z direction and when it is close to the table, it drops the part.

The process loops for 10 minutes with an intermediate position of 0.5 m over the picking position.

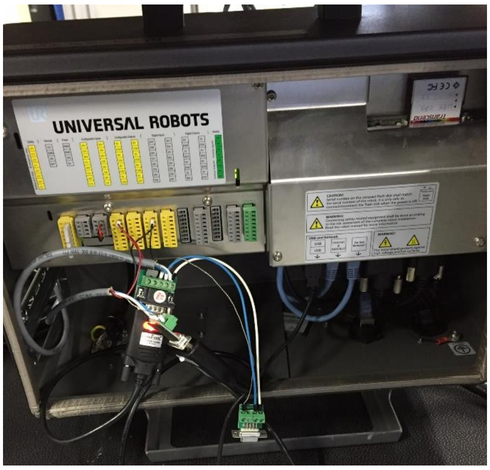
Figure 6: Example of Robotic Cell Description

3.2 Machine Control System Description

To make sure the control method is mastered, an identification of the robot controller is required. Since some robots can be controlled by different types of external controllers, each one of them being different in terms of safety features, it is important to list the controller model and which standard it is compliant with.

Refer to the risk assessment example as a template.

The robot control system provides servo driven motion control. The controller also has protective stops. and force and a power limiting safety function compliant with ISO 10218-1.



Picture 2: UR5 CB3 Universal Controler Main Control Panel

Figure 7: Example of Machine Control System Description for UR5 CB3

3.3 Machine Specifications

This section of the risk assessment describes the different technical data of the ''machine'', in this case, of the robot arm. This data can confirm a hazard or give further information on where to look for risk reduction. You can add more data to this section if necessary.

MACHINE LIMITS	
Machine Name/Type	Universal Robots UR5
Intended Environment:	Industrial
Required Training Level:	Basic Training
Operated by:	Operator, Maintenance Technician
Intended Use:	Materiel Handling
Machine Lifetime:	20 years
Machine Dimensions:	150mm x 80 mm x 170 mm
Machine Environment:	Manufacturing environment, dry, clean, non explosive, non flammable.

OPERATIONAL AND MAINTENANCE INFORMATION	
Operational Information	
Emergency Stopping Time:	<< 1 sec
Machine Cycle Time:	max speed 5000mm/sec, usually 1500mm/sec
No. of Operators:	1 in normal use
Maintenance Information	
Maintened by:	Trained permanent staff
Maintenance Frequency:	Daily
Cleaning:	Operator
Jamming Repair:	Operator
Housekeeping:	Amount required to be specified in: Information for Use.

POWER SOURCES	
Control, Elec. Supply:	24V DC, 220V AC
Main Feed, Elec. Supply:	Not Applicable
Penumatic Supply:	Not Applicable
Hydrualic Supply:	Not Applicable

Figure 8: Example of Machine Limits – Example for Universal Robots UR5

3.4 Device Specifications

Following the Machine Specifications section is the Device Specification section. Since the robot arm is considered as the machine, we often forget that the gripper or end effector can have different specifications than the robot itself. This is why a section of the risk assessment is dedicated to this device. If you have other external devices such as conveyors or if you want to list the specifications of a specific machine used by the robot, you are highly recommended to do so.

Again you can refer to the risk assessment example as a template.

3.5 Risk Estimation & Evaluation Criteria

In order to monitor and prioritize the different risks involved in the operation of the robot, you need to apply a numerical value to each identified hazard. There are a lot of ways to do this, we usually use the technique delineated by Pilz© that establishes rates for:

- Degree of Possible Harm
- Possibility of Occurrence of Hazard Event
- Possibility of Avoidance
- Frequency of Exposure.

With these four variables listed, you can calculate risk severity (negligible risk to high risk). Once all the risks are listed you can use this overview and criteria to prioritize which risk should be reduced first.

The Evaluation methodology based on *Pilz criteria* and experience, an evaluation of the factors, Degree of Possible Harm (DPH), Probability of Occurrence of a Hazardous Event (PO), Possibility of Avoidance (PA) and Frequency and/or duration of Exposure (FE), and has been performed on the risk related with each hazard. A Pilz Hazard Rating has then been calculated from the following formula:

PHR = DPH x PO x PA x FE

Where the above parameters can take the following values:

Degree of Possible Harm (DPH)

0.25	Scratch / Bruise
0.5	Laceration / cut / mild ill health effect/ minor burns
3	Fracture minor bone – fingers, toes
5	Fracture major bone – hand, arm, leg
8	Loss of 1 or 2 fingers/ toes or major burns
11	Leg / hand amputation, partial loss of hearing or eye
15	Amputation of 2 legs/hands, total loss of hearing/sight in both ears/eyes
25	Critical injuries or permanent illness/condition/injury
40	Single Fatality
65	Catastrophe

Possibility of Occurrence of Hazard Event (PO)

0.05	Almost impossible
1.25	Unlikely
2.5	Possible
4	Probable
6	Certain

Possibility of Avoidance (PA)

0.75	Possible
2.5	Possible under certain circumstances
5	Not Possible

Frequency of Exposure (FE)

0.5	Annually
1	Monthly
2	Weekly
3	Daily
4	Hourly
5	Constantly

The maximum and minimum numerical values that could be assigned to each factor for every hazard are shown in the following table.

Figure 9: Hazard Rating Calculation

Consider that once you have evaluated the Hazard Rating, you can follow the indication written in the Comment column of Figure 9. This will guide you as to which hazards to prioritize immediately and which ones you can leave untouched.

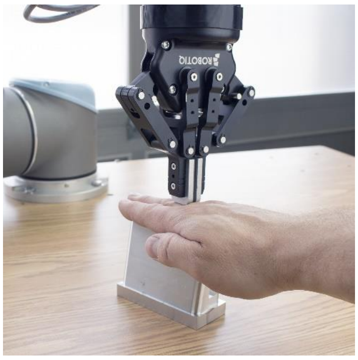
PHR		Risk	Comment
	1-10	Negligible Risk	Presents practically no risk to health and safety, no further risk reduction measures are required.
	11-20	Very Low Risk	Presents very little risk to health and safety, no significant risk reduction measures are required, may necessitate the use of personal protective equipment and/or training.
	21-45	Low Risk	Risk to health and safety is present, but low. Risk reduction measures must be considered.
	46-160	Significant Risk	The risk associated with the hazard is substantial enough to require risk reduction measures. These measures should be implemented at the next suitable opportunity.
	161-500	High Risk	Potentially dangerous hazard, which requires risk reduction measures to be implemented urgently.
	501+	Very high Risk	Risk reduction measures should be implemented immediately, corporate management should be notified.

Figure 10: Hazard Rating Grid – Action to take in accordance with hazard rating.

3.6 Findings

This section is one of the most important parts of the report. Findings summarize all the different potential hazards for the robotic cell. This section enumerates, evaluates and reduces the risk for each possible motion or action of the robot. We have listed a couple of examples to illustrate what we mean. However, since there is a long list of possible hazards and an even wider array of methods to respond to them, we have only provided a few possibilities. Take a look at the following figure to have a better idea of the methodology of risk identification and risk reduction.

Again you can refer to the risk assessment example as a template.

Hazard Identification		Hazard No.	1.1
Title	Part detection		
Location	Machine feed		
Target	Hand		
Activity	Normal operation		
Task	Part seeking		
Sub Task	Part grasping		
Hazard Type	Mechanical Hazard with the consequence of		
Sub Type	Crushing and impact (Quasi-static)		
Description	The UR5 'seeks' for a part with both fingers closed and stops when reaching a force threshold at a given height. The robot only starts its program if a part is detected. The force is monitored by a Robotiq FT 300 Force Torque Sensor. There is a possibility that a worker could place his/her hand between the Gripper and the part. The robot is running at a reduced speed of 20 mm/s and has a 10 N threshold to detect parts. Since the fingers are closed together, they have an area of (13.5 x 23 mm) 310.5 mm2 or 3,105 cm2. In case of an impact at 10 N, the pressure spread over this surface and applied by the Gripper fingers is (10 N/3.105 cm2) 3,22 N/cm2. This is equivalent to energy of 0.0001 J. With a maximum suggested pressure of 197 N/cm2 and 0.49 J of energy, this force and energy are slightly lower than levels permissible by ISO/TS 15066.		
References:	ISO/TS 15066, ISO 10218		

Risk Estimation and Evaluation			
Degree of Possible Harm:	0,5	Possibility of Avoidance:	0,75
Probability of Occurance of a Hazardous Event:	1,25	Frequency And/or Duration of Exposure:	4
Pilz Hazard Rating (PHR):	1,875	Summary Level:	Negligible Risk

Risk Reduction	Reference
Not necessary	

Risk Estimation and Evaluation			
Degree of Possible Harm:	n/a	Possibility of Avoidance:	n/a
Probability of Occurance of a Hazardous Event:	n/a	Frequency And/or Duration of Exposure:	n/a
Pilz Hazard Rating (PHR):	#VALUE!	Summary Level:	Negligible Risk

Figure 11: Example of hazard identification and risk reduction in a collaborative robot cell.

3.7 Priority Listing

You have now listed and rated as many possible hazards as can be realistically associated with the application; you can now order them in terms of priority. Since the most dangerous hazard should be reduced or eliminated first, you need to have a global view of which hazard should be worked on in which order. That is the main reason for this list.

Priority	Hazard No.	Hazard Name	PHR	Risk Level
1	1.3	Part dropping	75	Significant Risk
2	1.2	Part grasping	12,5	Very Low Risk
3	1.1	Part detection	1,875	Negligible Risk
4	…	…	…	…
5				

Figure 12: Example of Priority List – Applicable for the 3 examples listed by Robotiq

4 Risk Assessment Conclusion

Like all good documentation, you need to conclude the document with the next steps for the application. In this case, you need to list what actions will be taken to reduce or eliminate the risks you have identified to allow humans to safely work alongside a collaborative robot according to your risk assessment process.

Overall, the force limited collaborative mode operation can attain the risk level required for compliance to the ISO/TS 15066, however some of the risk sources listed in section 3.5 and 3.6 requires further risk reduction.

The overall changes required may be summarized as follows:
Reduce the robot force setting in the safety settings
…

Québec City, Qc, CAN
11 April 2016

Figure 13: Example of Risk Assessment Conclusion

5 Other Attached Documentation

To complete the risk assessment process, we highly recommend you attach supporting documentation or further explanations. We have provided a lexicon and an abbreviation lexicon. It is also suggest that you link your assumption to established standards. For each risk reduction process or other similar process, a proof should be cited (if necessary). In the example of this eBook, most references are directly written in the risk reduction process.

CONCLUSION

The risk assessment for collaborative robots is an iterative process with a lot of room for interpretation. To reduce the risk of potential harm, in a human robot collaboration, standards and best practices have been introduced specifically for this type of robot. With the information and examples presented in this eBook and with the *Risk Assessment for Collaborative Robots: An Introduction* eBook, we hope to provide some direction when performing your own risk assessment or a greater understanding of what needs to be accomplished when you have a risk assessment performed for you.

Keep in mind: we are not a risk assessment firm and this information is only provided as a guide and to initiate discussion. For more relevant information specific to your particular situation you should contact your local robot integrator, who can determine which regulations should apply for a proper risk assessment for your application.

SOURCES

Collaborative Robots Risk Assessment; An Introduction, Robotiq, Verison 1.1, Consulted April 2016

ISO 10218 : 2011 – Robots and robotic devices – Safety requirements for industrial robots (Part 1 & 2), ISO, Consulted April 2016

ISO/TS 15066 : 2016 - Robots and robotic devices – Collaborative Robots, ISO, Consulted April 2016

Industrial Safety Requirement for Collaborative Robots and Application, ABB, Consulted August 2015

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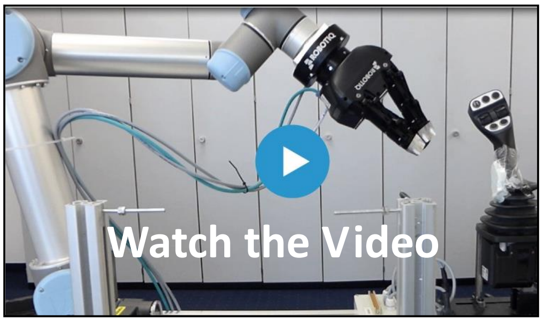
Universal Robot Risk Assessment – Performed by Pilz for Universal Robots USA, Consulted April 2016

Popular Applications

Machine Tending

Use a **single, programmable,** [flexible robot gripper] to handle a wide variety of parts in your machine tending applications. **Reduce your tooling cost** and **eliminate changeovers** by using a single Gripper.

Product Testing



Implement a **flexible** production line testing application that uses an easy to integrate Adaptive Gripper designed to control grip force and be able to adapt to various geometries.

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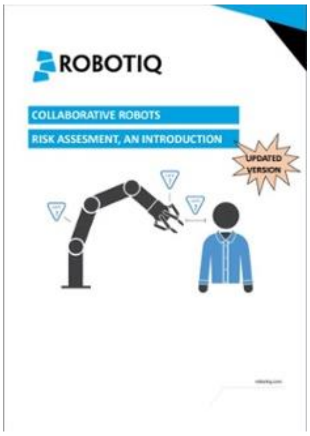
Getting Started with Collaborative Robots



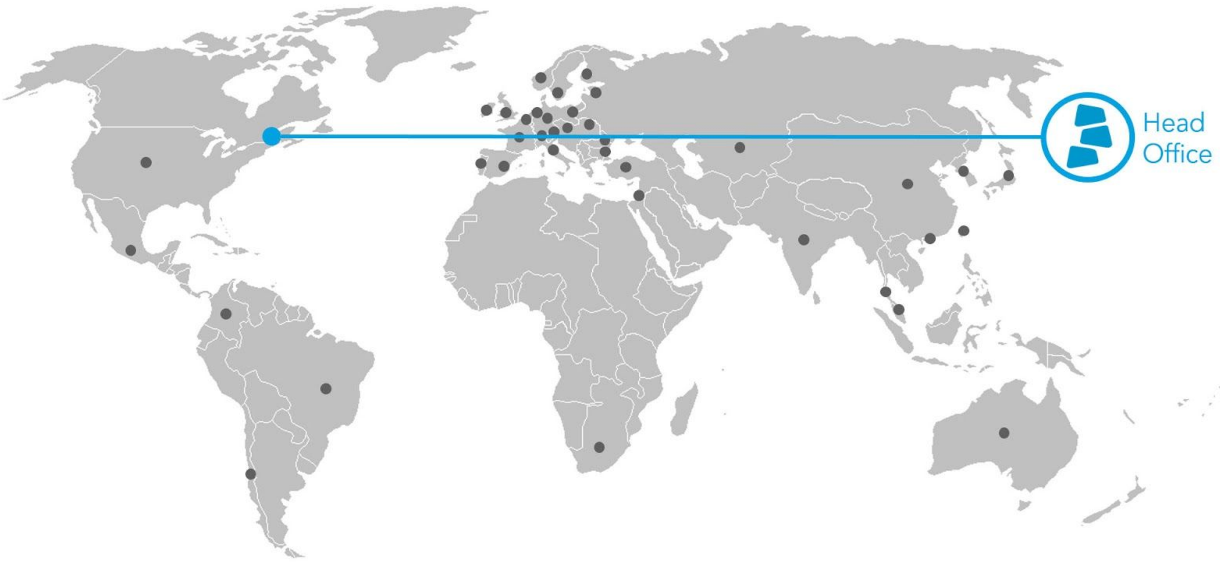
Collaborative Robots Risk Assessment, An Introduction

About Robotiq

Robotiq's Lean Robotics methodology and products enable manufacturers to deploy productive robot cells across their factory.

They leverage the Lean Robotics methodology for faster time to production and increased productivity from their robots. Production engineers standardize on Robotiq's Plug + Play Components for their ease of programming, built-in integration, and adaptability to many processes. They rely on Flow's software suite to accelerate robot projects and optimize robot performance once in production.

Robotiq is the humans behind the robots: an employee-owned business with a passionate team and an international partner network.



Let's Keep in Touch

For any questions concerning robotic and automated handling or if you want to learn more about the advantages of using flexible electric handling tools, contact us.

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D o F

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