C&E ADVANCED TECHNOLOGIES

Sensors

Safety

Vision

Motion

Automation

Controls

Robotics

Risk Assessment, Collaborative Robots, and Engineered Control-Devices

Your presenter is:
Heinz Knackstedt
C &E Safety Specialist

TÜV Functional Safety Engineer – Machinery
hknackstedt@CEAdvancedTech.com
(937) 434-8830 Office
(937) 545-6494 Cell

A Single Source…A Total Solution

C&E ADVANCED TECHNOLOGIES

Sensors

Safety

Vision

Motion

Automation

Controls

Robotics

Sensing/Connectivity

Safety

Vision

Motion

Automation

Controls

Robots

A Single Source…A Total Solution

C&E ADVANCED TECHNOLOGIES

Sensors

Safety

Vision

Motion

Automation

Controls

Robotics

Providing automation solutions since 1978

34 knowledgeable Technical Consultants covering Ohio, Kentucky, Indiana, and Tennessee

Same day shipment on stock items

24 hour product availability and technical support

On-line ordering

Non-warranty repair needs

Product training and awareness through seminars, workshops, lunch & learns and webinars – check out our event schedule at www.cesales.com

A Single Source…A Total Solution

C&E ADVANCED TECHNOLOGIES

Sensors

Safety

Vision

Motion

Automation

Controls

Robotics

Who we are and what we do

Forty years serving the automation industry

34 Technical Consultants who live near their customers

12 Technical Support Specialists, both in the field & in the office

12 Customer Service Reps, quotes, delivery information, expediting

Large inventory; same day shipping on stock items, 95%+ on time delivery

Order online, via EDI, Credit Card, Fax, or Phone

24 Hour emergency assistance

Lunch & Learns, Seminars, Webinars, and in-depth training classes

- **Generic Technology or Product application specific**
- **Webinars archived on-line**

www.cesales.com 800-228-2790

A Single Source…A Total Solution

Goals for the day

- Review the need for and the background of risk assessment
- Identify the “soft side” of risk reduction and what makes a risk reduction measure effective
- An overview of the major steps of the risk assessment process
- Introduce the concept of collaborative robots, what they are and are not, and their application risk reduction strategies

Employee Safety

- Occupational Health and Safety Act -1970 Public Law 91-596 (OSHA)
  - Act Applies to <u>User</u> (Employer) of a piece of equipment,
  - Not its Manufacturer or System Integrator
    - Subject to Civil Court Tort litigation for machine or integration
  - Federal law
    - Written and passed by Congress
    - Administered by either Federal or State OSHA
  - General Duty Clause 5.a

Each employer shall furnish to each of his employees, employment and a place of employment, which is free from recognized hazards that are causing or are likely to cause death or serious physical harm

Risk Assessment

Risk Assessment is the:

- SINGLE MOST IMPORTANT step in providing effective machine and plant safety because it:
  - Identifies the possible hazardous situations encountered while performing a specific task,
  - Determines the level of risk for that task
  - Identifies the requirements of the risk reduction measure(s) which will reduce the risk of that task to an acceptable level
  - Leads to the implementation of the risk reduction measure which achieves acceptable risk

The goal of the
Risk Assessment process is to
reduce risks to
acceptable levels

The Risk Assessment
PROCESS is not completed
until acceptable risk is achieved

Risk Assessment Objectives

- Reduce the rate and severity of injuries
- Increase understanding of the hazards and risks of Plant's Operations
- Identify risk reduction measures which:
  - Reduce Risk
  - ☆ Increase or maintain operational efficiency through correctly specified and designed, risk reduction measures
  - Are compatible with plant operations
  - Will be utilized by affected individuals
  - Assure cost effective, sustainable, solutions
- Install, validate, and maintain the risk reduction measures identified

Risk Assessment

- There is no Federal requirement for a <u>formal</u> Hazard Risk Assessment
  - OSHA only requires that risks be “assessed and reduced”

But

☆ Inspectors ask for documentation to show that this assessment and reduction has been accomplished

- All new and updated Consensus Safety Standards for machinery, now require a Risk Assessment
- Risks must be identified, understood, estimated, evaluated, and ultimately reduced to an acceptable level
- Develop a Risk Reduction measure, which accurately defines how the risk is to be reduced to an acceptable level, for each hazardous situation,

B11.0-2010
Safety of Machinery – General Requirements and Risk Assessment

There is no such thing a “ZERO” risk

Acceptable Risk.

- A risk level achieved after risk reduction measures have been applied. It is a risk level that is accepted for a given task (hazardous situation) or hazard
- The expression “acceptable risk” usually, but not always, refers to the level at which further technologically, functionally, and financially feasible risk reduction measures or additional expenditure of resources will not result in a significant reduction of the risk.

Risk Assessment
Option

- Use a Consultant who provides a Risk Assessment document as a deliverable for a fee
  - Advantages
    - Consultant is an “expert” at hazard identification, risk reduction, and safety standards
    - Requires less plant manpower resources
  - Disadvantage
    - Does not have the operational knowledge of the plant
    - Not familiar with current plant safety issues
    - Tends to provide a Hazard Identification and standard risk reduction solutions which may not be tailored to machine or plant’s operational needs
    - Difficult to update R.A. after a process or machine change

Risk Assessment
Option

- Conduct a risk assessment using an In-Plant team
  - Advantages
    - Heightened awareness of tasks, hazards, and risks
    - Best risk reduction measure is often a machine or process change which could also increase operational performance
    - Group consensus typically provides the best operational solution
    - Increased acceptance of risk reduction measures when developed with <u>input from operations personnel</u>:
      - Most familiar with operational requirements
      - Aware of “undocumented” tasks
    - Data available for other processes/machines or update
  - Disadvantages
    - Requires management commitment to empower team
    - Requires plant manpower resources

C&E ADVANCED TECHNOLOGIES

The “Soft Side” issues of risk reduction

Risk Assessment

Plant Operations have a major impact on the selection and effectiveness of risk reduction measures

Required: A Paradigm Shift FACT!

- There is NO plant which has not recently had an accident !!
- An accident is any UNPLANNED or UNEXPECTED outcome of an event, usually undesirable
  – It does not necessarily result in an injury
  – A near miss is an accident which, if repeated through continued exposure, will ultimately result in an injury
    - All of the factors which resulted in a near miss at one exposure to the hazard, might not be present in the same measure to prevent an injury at the next occurrence
  – The majority of injuries are preceded by unresolved close calls or near misses
    - There are between 7 to 9 “Close Calls” for every 1 Injury

Poor design is most often the <u>root cause</u> for the circumvention of safeguarding devices and risk reduction measures

"Value" Analysis by the Operator

<u>Perceived</u> **Risk and its resultant** ***<u>Reduction</u>***

....vs....

<u>Effort to Use</u> **the Risk Reduction Measure**

- **Influences impacting Safety Behavior**
  - **Perception**
    - **How dangerous is it now, what is my personal risk ?**
    - **How much is my risk reduced if I use the risk reduction measure?**
  - **Habit**
    - **I've always done it this way " 'cause that's the best way"**
  - **Obstacles**
    - **The risk reduction measure makes it more difficult to ……..**
  - **Barriers**
    - **The risk reduction measure prevents me from ……**

"<u>Understanding Influences on Risks: A Four-Part Model</u>" Terry Mathis, Shawn Galloway ProAct Safety EHS Today 10 Feb 2010

☆ ***Without a "Value" the risk reduction measures will not be used***

A "GOOD" risk reduction measure addresses these concerns

Use of risk reduction measures and means

- The most effective method of preventing defeating or bypassing of a risk reduction measure is to <u>remove the incentive</u> to do so

- Provide special machine operating modes with their own risk reduction features to assure that specific tasks may be carried out safely and easily, without circumvention of risk reduction measures

EX: MIG welder: Provide special manual operating mode for feeding weld wire which removes power from all unnecessary components and other equipment but provides manual control of those required for the job, such as a jog function for the wire feed rolls.

If torch is mounted on a robot, provide a "dress tip" position at a small opening in the perimeter fence which removes the need for the operator to enter the safeguarded space

Incentive to Defeat Safeguards

Benefits without protective device:
0 None + Minor ++ Substantial

IFA
Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung

Brief instructions:
1. Add operating modes if appropriate
2. Determine relevant tasks
3. Complete blue cells line by line

Modes of operation

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Tasks:	Automatic	Setup	Manual	etc.	etc.	Task permissible in these modes of operation?	Task possible without tampering?	Easier/more convenient	Faster, greater productivity	Greater use, e.g. for larger workpieces	Greater precision	Better visibility	Better audibility	Less physical effort	Reduced travel	Greater freedom of movement	Improved flow of movement	Avoidance of interruptions	etc.	Incentive to bypass for the task
2	Help	Help					Help	Help	Help												Help
3	Initial Operation																				
4	Program test/ test run																				
5	Setup/adjustment conversion/tooling/																				
6	Machining																				
7	Manual intervention for swarf removal																				
8	Manual change of workpiece																				
9	Manual intervention for trouble shooting																				
10	Checking/random sampling																				
11	Manual intervention for measuring/ finetuning																				
12	Manual change of tools																				
13	Maintenance/ servicing																				
	Rectification of faults																				

Cause for Manipulation (Defeating) of Safeguarding Devices and Measures

Result of many of Machine Injuries due to Functional Safety Specification Errors

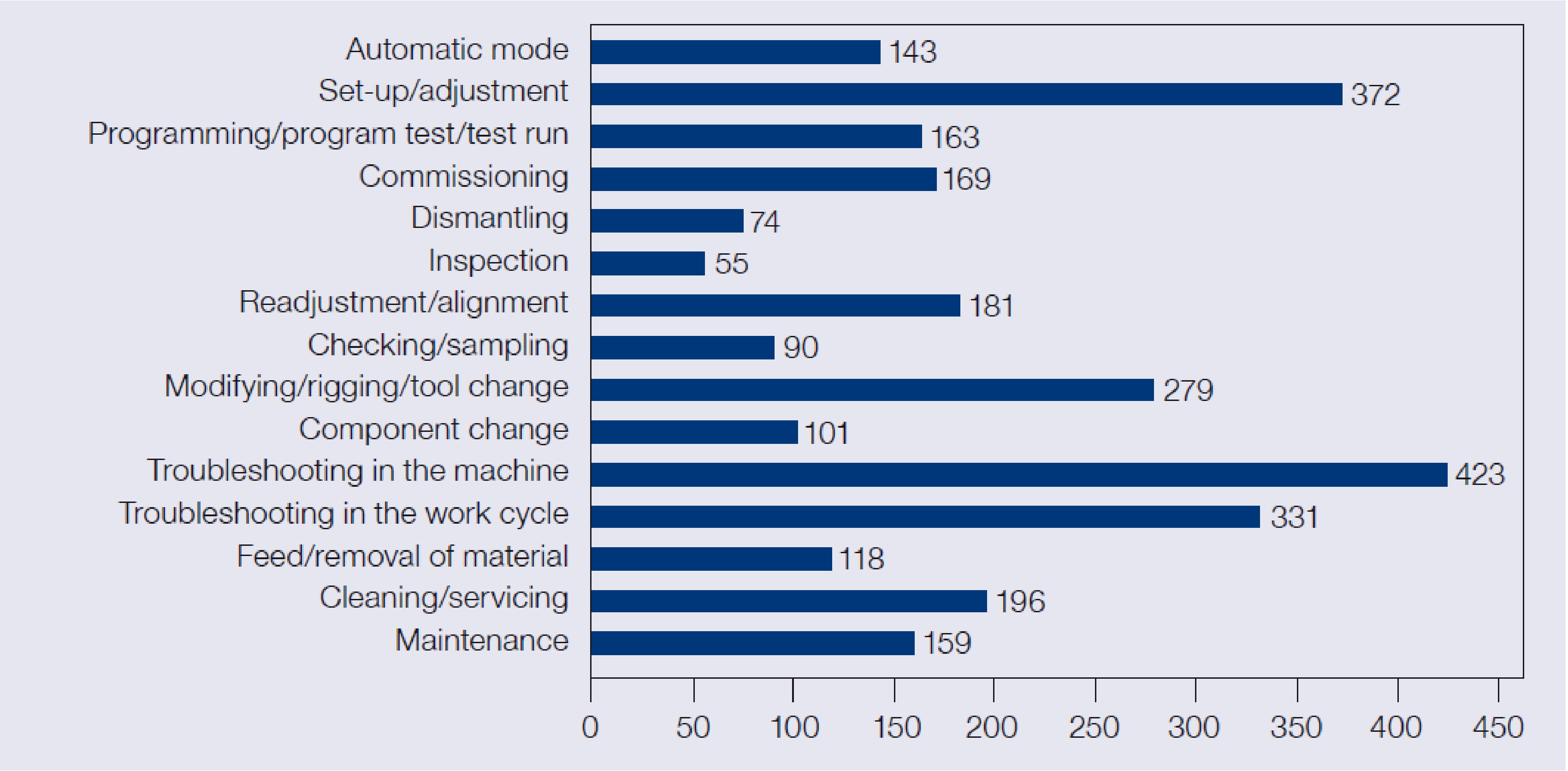


Fig. 12 Subjectively perceived “necessity” of manipulating protective devices according to operating modes (n = specifications as part of an empirical study; multiple answers possible)

Taken from Best of MRL-News “Safety of Machinery and Machine Control Systems” Schmersal/Elan publications Apr 2011

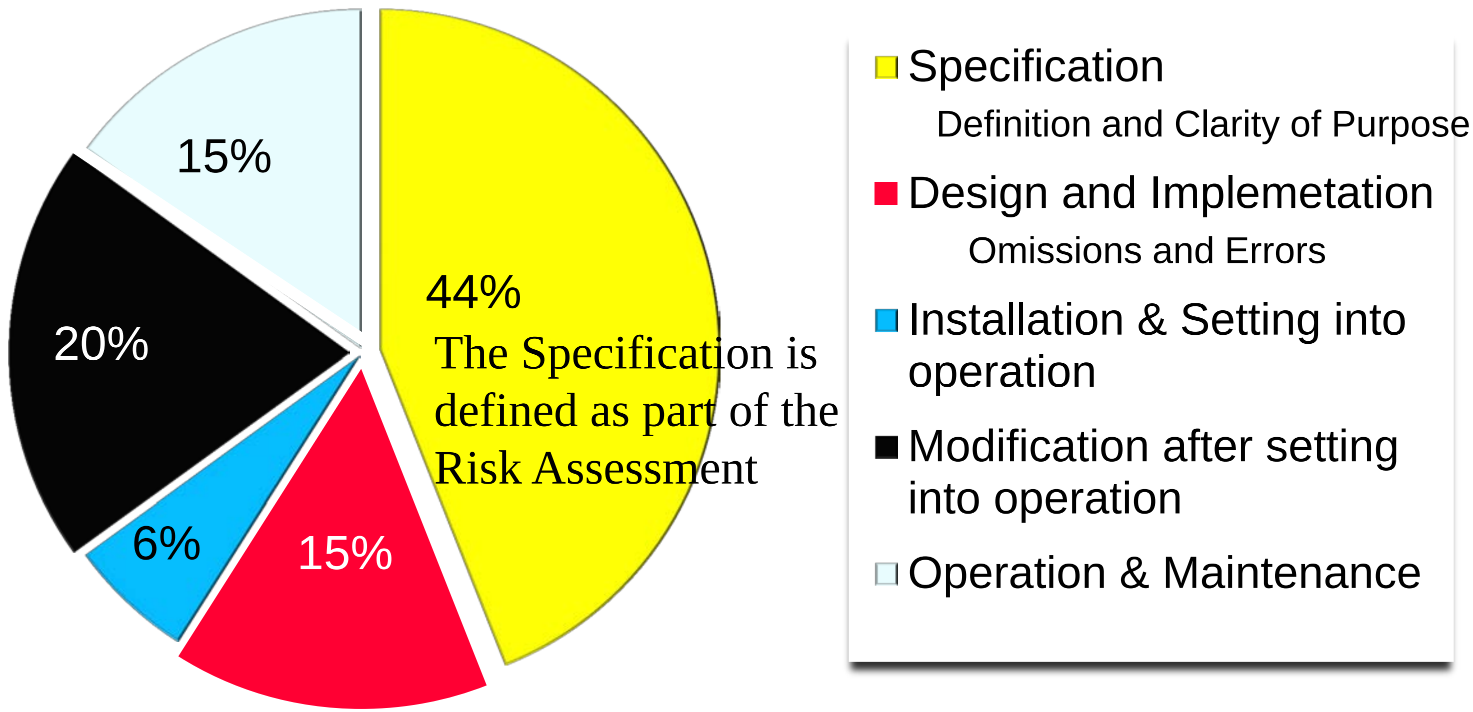
C&E ADVANCED TECHNOLOGIES

The value of a complete and thorough Risk Assessment

Causes of Process Safety Incidences
Safety Related Parts of the Control System (SRP/CS) did not provide the Required level of Risk Reduction

85% ~~65%~~ Already wrong before start of operation. These are **Quality** issues not Hardware Failures. Systematic errors which must be Reduced by Fault Avoidance through specification and design quality measures and Validation

Errors in concept caused by lack of understanding of the task(s)



ONLY 15% ARE FROM OPERATIONS AND RANDOM FAILURES

C&E ADVANCED TECHNOLOGIES

Source: "Out of Control" UK Health and Safety Executive (HSE) (September 2004)

Risk Assessment

The Process

An Overview

Risk Assessment - the Process

- Objective is not just to assess risk but to reduce the risk to an acceptable level
- Identify the machine life cycle for the Risk Assessment
  - Design, Build, Install, Commission, Operate, Maintain, De-commission, Dispose
- Determine the use limits of the machine or process
  - Function, Operation, Product, Material
- Identify Tasks
  - Operations located at, on, or near the machine/equipment
    - Include both Production and Repeated/Routine Maintenance
      - For major maintenance projects, do separate risk assessment for those tasks specific to that activity
  - Activities in the area affected by the machine or process

Risk Assessment, the Process

Continued

- Identify Users and their tasks
- Identify Hazards
  - All components and situations which can result in an injury if individuals are exposed
- Task / Hazard Pairs
  - For each specific **task,** identify all **hazards** or hazardous situations to which personnel can be exposed during its execution
- For each Task / Hazard pair :
  - Estimate the Risk
    - The level of risk from any one hazard may vary with the task
  - Evaluate the level of risk,
    - Is it acceptable or must it be reduced?

Risk Assessment, the Process

Continued

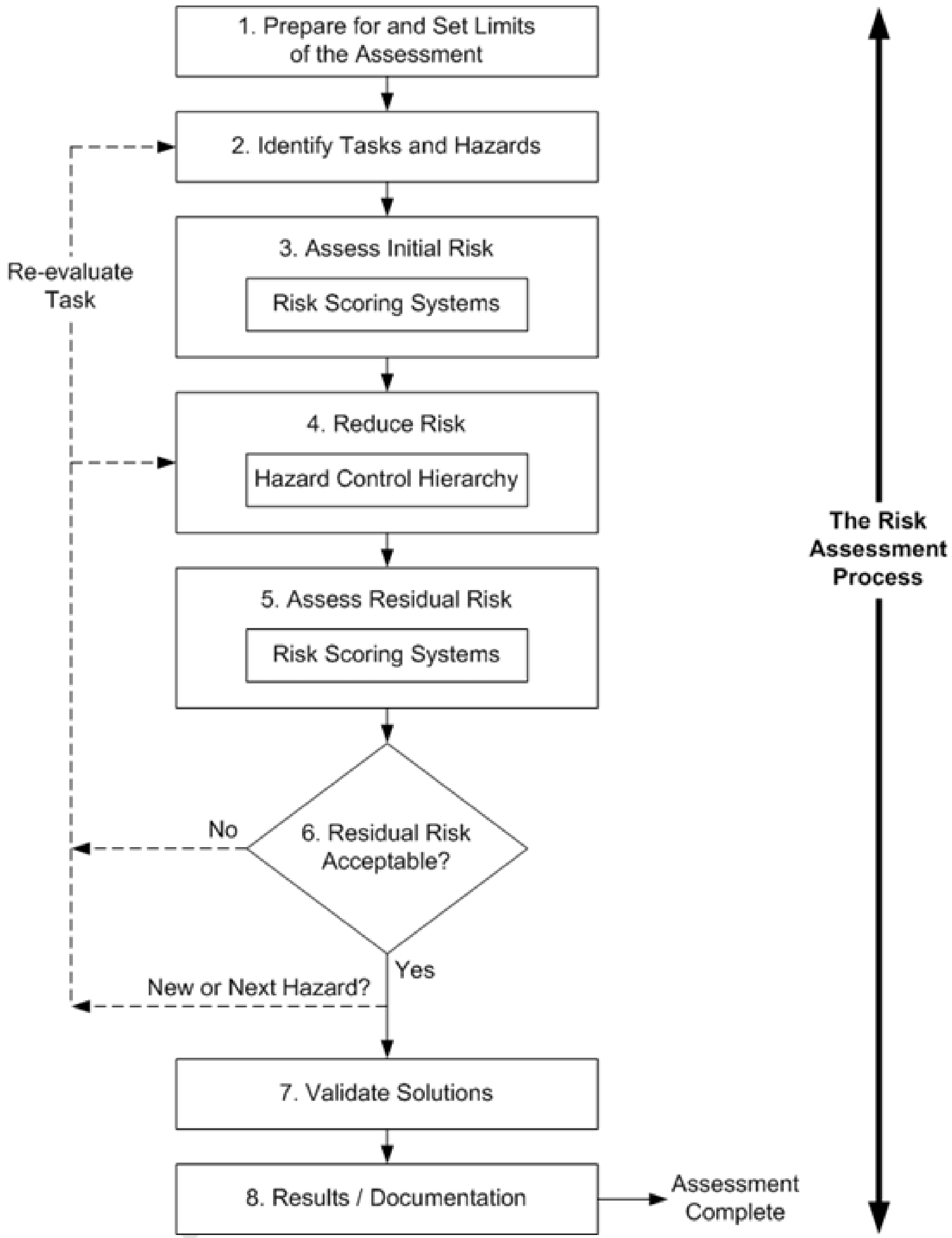
- For each Task / Hazard pair with unacceptable risk:
  - Identify possible risk reduction measures, and choose the most applicable
  - Verify that the risk reduction measure chosen:
    - Reduces the risk to an acceptable level
    - If Functional Safety, meets the required performance level
  - Repeat process until acceptable residual risk is achieved

Risk Assessment, the Process

Continued

- Develop risk reduction implementation plans and track their progress
- Develop Validation plans of how the actual performance of the implemented risk reduction measures may be tested safely and completely
- Develop and implement training program on correct use of the risk reduction measures
- Document and track performance and utilization of installed risk reduction measures

Risk Assessment Process



ANSI/B11.0 Figure 6 — The Risk Assessment Process

Risk Assessment
The details

Attitude/Equipment/Components for an IN PLANT Risk Assessment

- **Enthusiastic support from upper management**
  - For Safety
  - For Change
  - For the Risk Assessment process
  - For the implementation, utilization, and maintenance of identified risk reduction solutions
- Diverse, knowledgeable, and interested team which can work together to reach a consensus
- Clear team understanding of any special rules or limits
- Facilitator who, has no vested interest in specifics of the outcome, but will manage the Risk Assessment **Process** to assure that:
  - **Brain Storming is used to identify possibilities**
  - **All views are solicited, presented, and fairly evaluated,**
  - **Consensus is reached to obtain a risk reduction solution**
- Methodology to evaluate and track risks and risk reduction
  - Optional commercial Risk Assessment Software

Risk Assessment, Estimation

- There are a number of Risk Estimation procedures and rating systems
  - Each seeks to use the variables of:
    - Severity of injury
    - Probability of that harm
  - Together, these identify a relative level of risk
    - Risk = Severity * Probability of harm
- ***The choice of the risk estimation tool is less important than the process itself.***
  - ***The benefit of Risk Assessment comes from the discipline of the process rather than the absolute accuracy of the results***
- Resources are better spent on actual risk reduction rather than attempting to attain absolute precision in the estimation of the risk

Identify the Users and their Tasks

- Operations
  - Automatic, Manual
- **Interventions are normally the most dangerous as they may be unpredictable and are frequently unplanned**
  - Tooling jams, bad material, broken tools, incorrect set-up, material feeder jams
- Set-up and changeover
- Minor Maintenance and adjustment, lubrication, replacing wear items
- Movement of consumables, productive material, waste material, and finished goods
- Loading process components and supplies
- Trouble shooting the process or machine
- Cleaning
- Foreseeable misuse
- Activity in the vicinity of the machine
  - Truck/Fork Lift traffic with process materials and finished goods
  - Passers by

Identify the Hazards

- For a Risk Assessment on installed equipment, **mentally** remove all risk reduction measures
  - These may be retained as a risk reduction measure, if they meet the requirement, as determined by the Risk Assessment
- Shear, Cut, Crush, Pinch, Entrap, Strike, Puncture, Burn
- Trip, Slip, Fall
- Electric, Pneumatic, and Hydraulic, energy
- Gravity, Radiation, Thermal, Trapped or Residual energy
- Ejected tools or materials
- Ergonomic
  - Lifting, Repetitive motion
- Environmental hazards
  - Smog, Weld Slag, Plating and Washing Waste Water
  - These often change with material being processed, such as hazardous smog while welding galvanized vs mild steel

Identify all hazards or hazardous situations to which individuals can be exposed while performing each task,

including foreseeable misuse

Each is a TASK/HAZARD PAIR

Estimate the Risk

- Risk is a combination of:
  - Most likely Severity of Injury

    and
  - Probability of Occurrence of that Harm
    - Frequency and length of exposure to the hazardous situation
    - Ability to avoid the injury
    - Probability of the occurrence of the hazardous situation
- Specialized Skills or Training may **NOT** be used to reduce the risk in the initial estimation of the risk
  - Training may be used to reduce risk BUT only after the innate risk has been correctly estimated, training identified, and when implemented as a part of the risk reduction measures
- The risk from a given hazard may vary depending on the exposure during one task versus another
- Standards and many Risk Estimation tools are available which relate task/hazard pairs to their level of risk

C&E ADVANCED TECHNOLOGIES

Selection Criterion and Guidelines

- Select injury severity which is the <u>most likely</u>, not the worst conceivable.
  - The occurrence probability is for that level of severity
- Exposure due to Frequency or Duration
  - Based on the assumption that exposure ultimately leads to injury
    - Frequency, how often is an individual exposed to the hazard
    - Duration, how long is the individual exposed to the hazard
- Probability of Occurrence
  - History of **accidents** in similar circumstances
    - <u>Near Misses should be viewed as hazardous events</u>
    - Under what conditions will the hazard be present
      - Always, sometimes, seldom, only if something else fails
  - What is the possibility to escape the hazard and avoid the injury
    - Warning, Speed, Clearances,
    - **General** Knowledge of Individual(s)

Examples of Level of Risk Estimation Methodology

ANSI/B11.0- 2015 (Annex – D) Table 11 — ANSI / ASSE Z10 Risk Scoring Matrix

Or Activity	←--------Severity of Injury or Illness Consequence------→			
Likelihood of OCCURRENCE or EXPOSURE for selected Unit of Time or Activity	NEGLIGIBLE	MARGINAL	CRITICAL	CATASTROPHIC
Frequent	MEDIUM	SERIOUS	HIGH	HIGH
Probably	MEDIUM	SERIOUS	HIGH	HIGH
Occasional	LOW	MEDIUM	SERIOUS	HIGH
Remote	LOW	MEDIUM	MEDIUM	SERIOUS
Improbable	LOW	LOW	LOW	MEDIUM

Likelihood:
Frequent: Likely to occur repeatedly
Probable: Likely to occur several times
Occasional: Likely to occur sometime
Remote: Not likely to occur
Improbable: Very unlikely – may assume exposure will not happen

Severity/Consequence:
Negligible: First Aid or Minor Medical Treatment
Marginal: Minor injury, lost workday accident
Critical: Disability in excess of 3 months
Catastrophic: Death or permanent total disability

Risk Level:
LOW: Risk Acceptable, Remedial Action Discretionary
MEDIUM: Take Remedial action at appropriate time
SERIOUS: High priority remedial action
HIGH: Operation not permissible

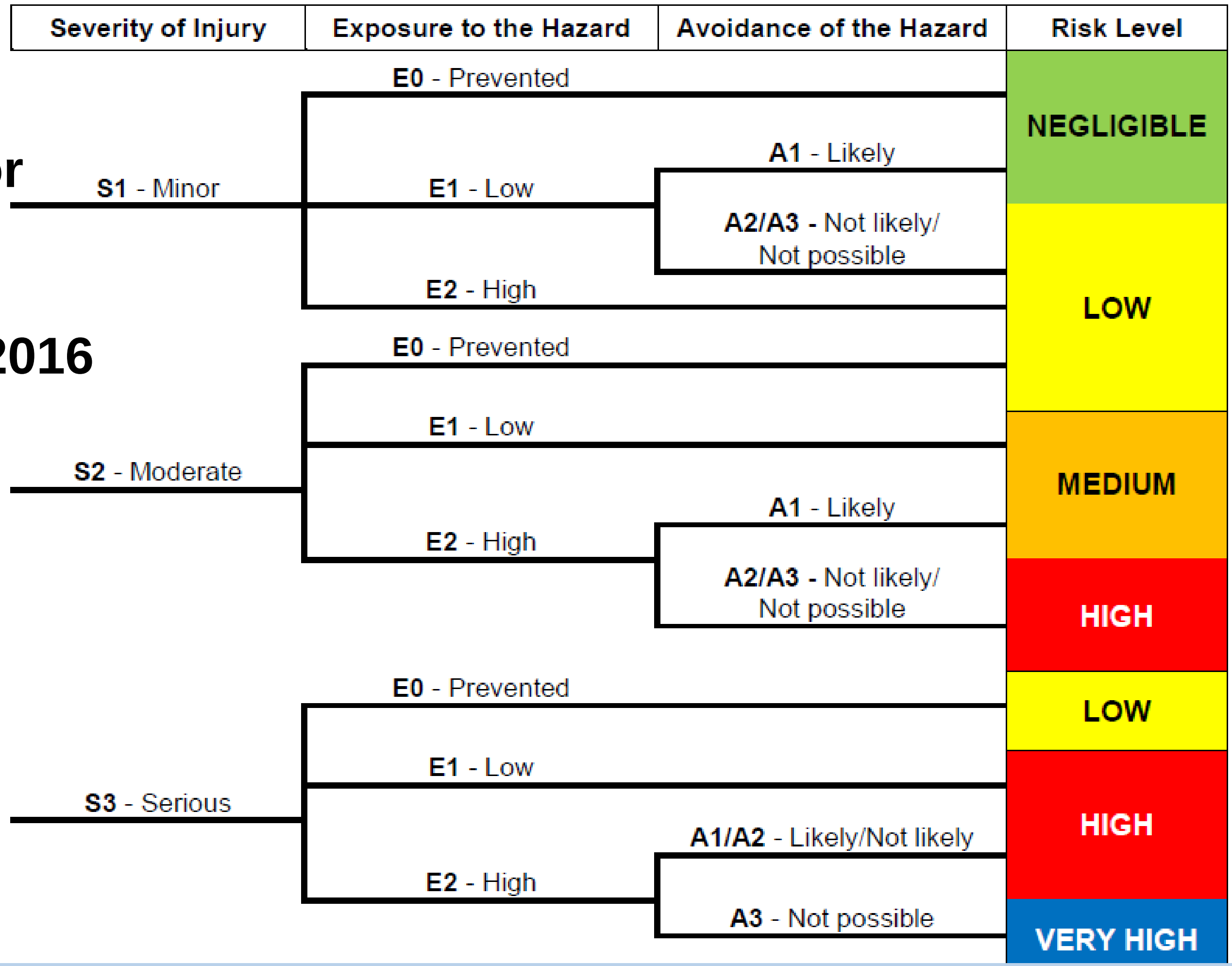
Note: these definitions are provided for illustrative purposes only, and each organization will need to define these terms for their own risk assessment process

Example of a Risk Estimation Tool

Risk Assessment for Robots from ANSI/RIA TR R15.306-2016

Task/Hazard Pair

Table 2 – Risk level decision matrix



C&E ADVANCED TECHNOLOGIES

Example of terms for Risk Estimation

Risk Assessment from ANSI/RIA TR R15.306-2016

Table 1 – Injury severity, exposure, and avoidance factors

Factor	Rating	Criteria (Examples) – choose most likely *Read criteria from the top for each factor*
Injury Severity	**Serious S3**	Normally non-reversible; likely will not return to the same job after recovery from incident: – fatality – limb amputation – long term disability – chronic illness **If any of the above are applicable, the rating is SERIOUS**
	Moderate S2	Normally reversible; likely will return to the same job after recovery from incident: – broken bones – severe laceration – short hospitalization – short term disability – lost time (multi-day) – fingertip amputation (not thumb) **If any of the above are applicable, the rating is MODERATE**
	Minor S1	First aid; no recovery required before returning to job: – bruising – small cuts – no loss time (multi-day) – does not require attention by a medical doctor **If any of the above are applicable, the rating is MINOR**
Exposure[1]	**Prevented E0**	– Exposure to hazard(s) is eliminated/ controlled/ limited by inherently safe design measures. – Use of guards prevents exposure or access to the hazard(s) (see Part 2, 5.10). If an interlocked guard is selected, the following bullet must also be met. – If functional safety is used as a risk reduction measure, the implemented functional safety performance (PL) meets or exceeds the required functional safety performance (PL_r). See Part 2, 5.2. **If any of the above are applicable, the rating is PREVENTED**
	High E2	– Typically more than once per day or shift – Frequent or multiple short duration – Situations which could lead to increases in the duration of a task, not to include teaching tasks **If any of the above are applicable, the rating is HIGH**
	Low E1	– Typically less than or once per day or shift – Occasional short durations **If either of the above are applicable, the rating is LOW**
Avoidance	**Not possible A3**	– Insufficient clearance to move out of the way and safety-rated reduced speed control is not used – The robot system or cell 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 or eruption hazard) **If any of the above are applicable, the rating is NOT POSSIBLE**
	Not likely A2	– Insufficient clearance to move out of the way and safety-rated reduced speed control is used – obstructed path to move to safe area – hazard is moving faster than reduced speed (250 mm/sec) – inadequate warning/reaction time – the hazard is imperceptible **If any of the above are applicable, the rating is NOT LIKELY**
	Likely A1	– 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 **If any of the above are applicable, the rating is LIKELY**

[1] E0, E2 and E1 are purposely presented in this order (see 6.4.1.2)

Risk Assessment

Evaluation of the Risk

Is current risk level acceptable?

“YES”

Potential Administrative measures to further reduce residual risk

Risk Assessment

Is current risk level acceptable?

"NO"

Current Risk Not Acceptable, You must Reduce the Risk

What risk reduction measures or methods will achieve acceptable risk ?

Before deciding on a Risk Reduction measure, review the requirement for use of Lock Out /Tag Out (LOTO)

LOTO vs *Alternative Methods* of Machine Risk Reduction for the Control of Hazardous Energy

- A risk assessment, to determine whether the task can and should be done under LOTO, <u>must precede</u> selection of all risk reduction measures which do not **directly** reduce the risk to an acceptable level through:
  - Hazard elimination or necessary level of risk reduction by design
  - Fixed guard which will not be removed to accomplish the task
  - An individual is not exposed to a hazard

Lock Out-Tag Out

To provide protection from UNEXPECTED energization, start up, or release of <u>hazardous</u> energy

ANSI/ASSP Z244.1-2016 provides additional guidance on the use and design of Alternative Methods when the Risk Assessment has established that total Lock-Out is not practicable for that task

C&E ADVANCED TECHNOLOGIES

Risk Mitigation / Reduction

- Risk Reduction Hierarchy
  - List of actions is in descending order of effectiveness at reducing or managing the risk

1. Elimination by redesign/substitution
2. Reduction by **irreversible** redesign/substitution
   - Reduce severity of injury
     - Reduce available Force
   - Improve ability to escape
     - Reduce maximum speed
   - Reduce frequency of exposure
     - Change process or location of task
3. Fixed Guards
4. Safeguarding Devices
5. Awareness Devices
   - Active
   - Passive
6. Training and Procedures
7. Personal Protective Equipment

Directly impact the hazard (items 1–2)

Functional Safety (items 3–5 Active)

Depends on action of personnel to be effective (items 5–7)

Functional Safety

- The use of control-devices, logic, and circuit design to prevent exposure to the hazard
  - Control hazard to attain a lower level of risk
    - Sequenced multiple forces or speeds
  - Attain a safe state before hazard can be reached
  - Prevent access to by physical control (lock) until the hazard has reached a safe state
- Functional Safety depends on the proper functioning of components and systems for the risk reduction
  - A Fixed Guard is not Functional Safety
  - An interlocked guard which shuts down the drive of a hazardous machine is Functional Safety
- The failure to danger of a Functional Safety system, increases the risk **Back to its initial level**

C&E ADVANCED TECHNOLOGIES

The simple Truth

- If nothing ever failed, any circuit which eliminated the hazard would be acceptable, regardless of the level of risk that the hazard represented
- BUT………………………..!

CAUTION

HOPE **is not a safety strategy!**

Is that the Back-Bone of your Safety Program?

Risk Level and Functional Safety

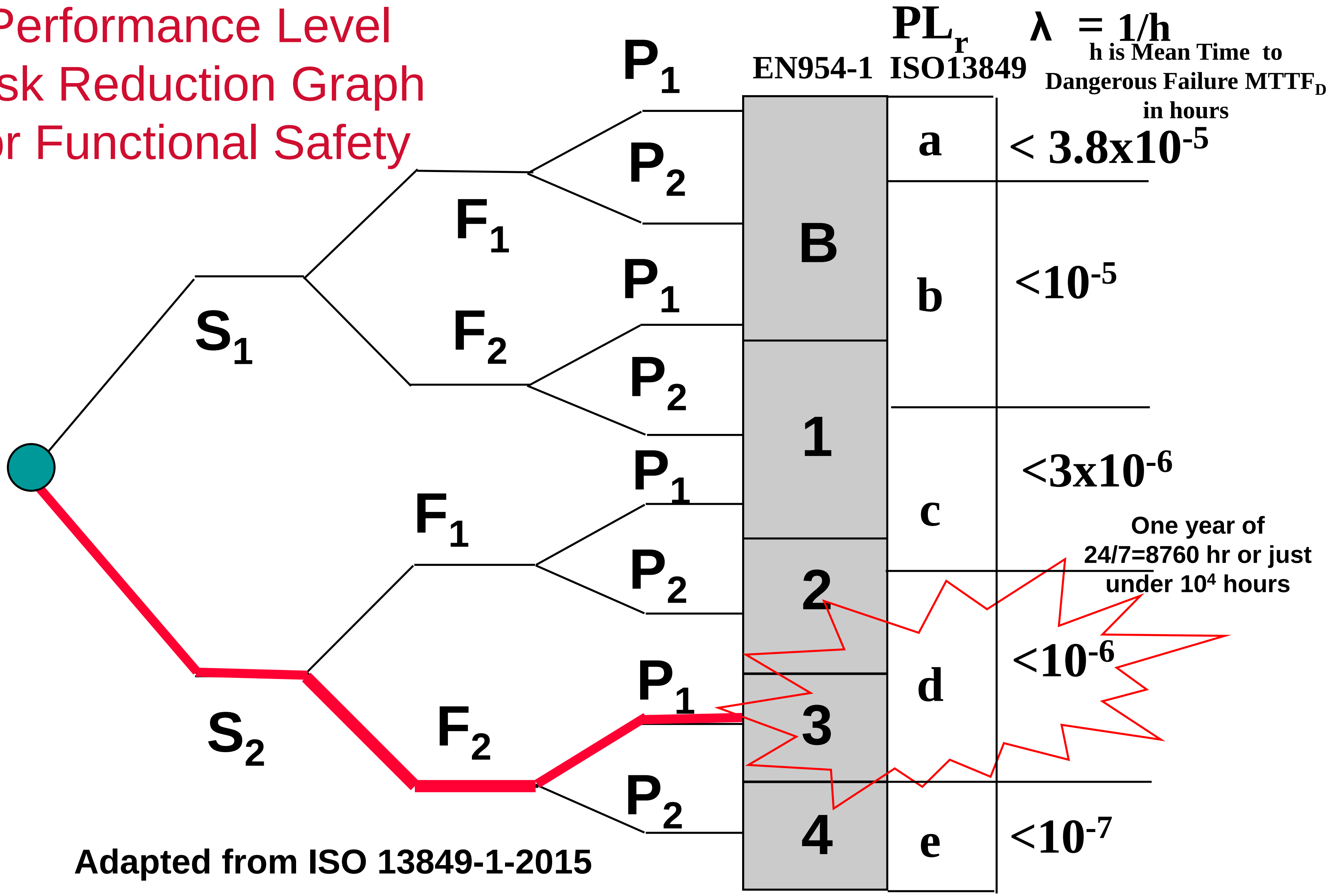
- The higher the level of risk, the more reliable the Functional Safety System design must be to prevent the loss of the safety function due a failure to danger of any of its components
- There are only three results of a failure to danger of a safety function component
  - Detection, reaching a safe state, and system repair
  - A close call or near miss accident
  - An Injury accident
- If Functional Safety is to reduce a given risk to an acceptable level
  - It must be designed with the appropriate reliability performance level and withstand component failures with an acceptable result

Correlation of Level of Risk Reduction required, to a Functional Safety System's Circuit Design

- Some risk assessment tools have a mapping technique to convert level of risk to an appropriate performance level (PL_r) of a functional safety circuit
- Machine safety design standards may contain mapping, which takes variables similar to those identified in the risk assessment, to identify the performance level requirement of the functional safety circuit

C&E ADVANCED TECHNOLOGIES

Performance Level Risk Reduction Graph for Functional Safety

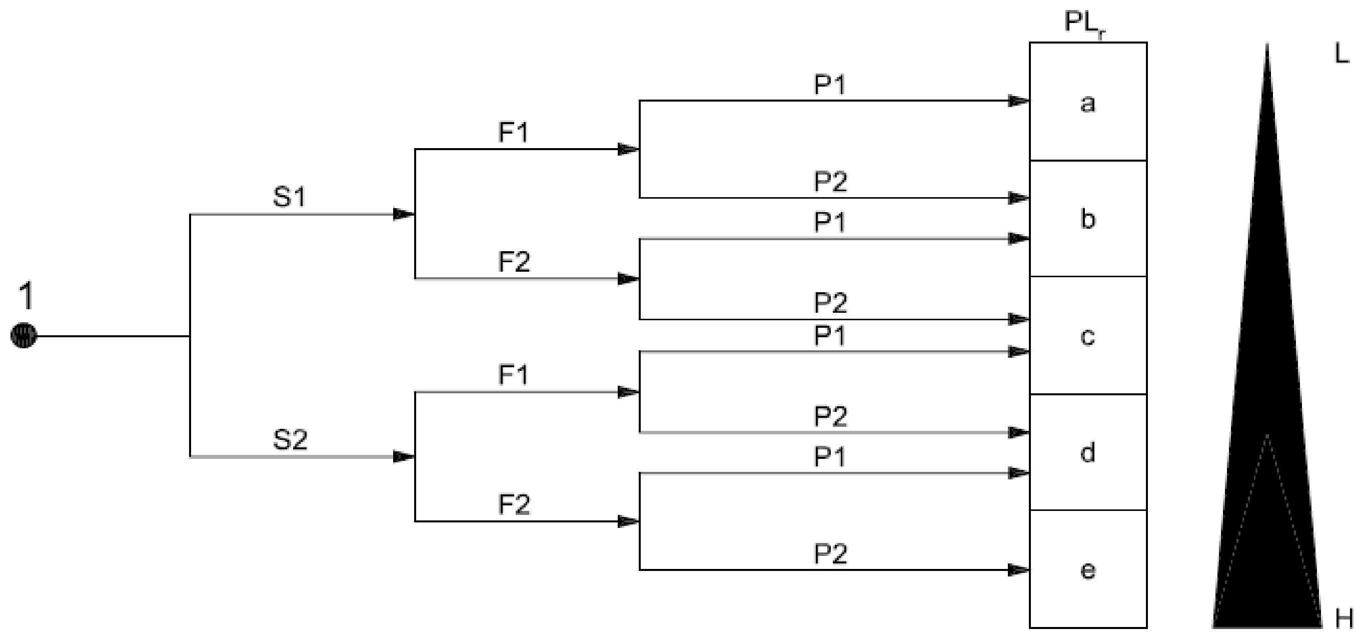


Adapted from ISO 13849-1-2015

Operation of a population of machines for a period equal to the MTTF$_D$ (λ) means that 63% of them will have experienced a failure to danger over that time period

C&E ADVANCED TECHNOLOGIES

Performance Level Risk Reduction Graph for Functional Safety



Key

1 starting point for evaluation of safety function's contribution to risk reduction

L low contribution to risk reduction

H high contribution to risk reduction

PL_r required performance level

Risk parameters:

S severity of injury

S1 slight (normally reversible injury)

S2 serious (normally irreversible injury or death)

F frequency and/or exposure to hazard

F1 seldom-to-less-often and/or exposure time is short

F2 frequent-to-continuous and/or exposure time is long

P possibility of avoiding hazard or limiting harm

P1 possible under specific conditions

P2 scarcely possible

C&E ADVANCED TECHNOLOGIES

ISO 13849-1 Annex A Figure A.1

A Map of Level of Risk to Performance level

For Robot Applications only

For Robot Applications only.
From RIA TR R15.306-2016

Relationship of the Risk Level to the Required Performance Level (PLr) of the SRP/CS

The SRP/CS performance is based on ISO 13849-1

Table 5 – Minimum functional safety performance

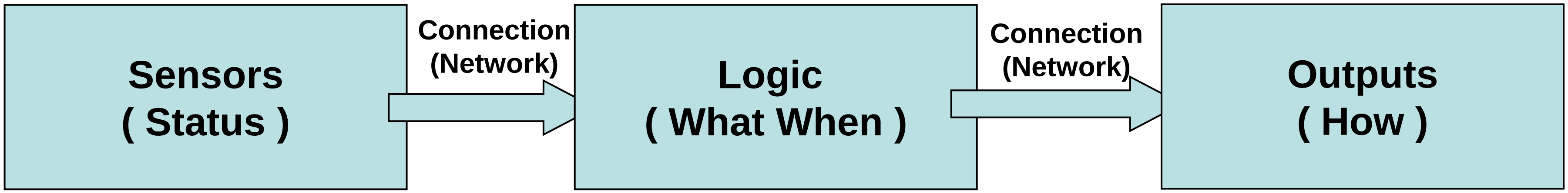
Risk Level	PL_r	Structure Category
NEGLIGIBLE (see 6.5.3.1)	b	-
LOW	c	2
MEDIUM	d	2
HIGH	d	3
VERY HIGH (see 6.5.3.2)	e	4

SRP/CS requirement for risks meeting NEGLIGIBLE risk level

Table 5 Minimum functional safety performance requirements as function of the risk level ANSI/RIA TR R15.306:2016

<u>**S**</u>afety <u>**R**</u>elated <u>**P**</u>art of the <u>**C**</u>ontrol <u>**S**</u>ystem

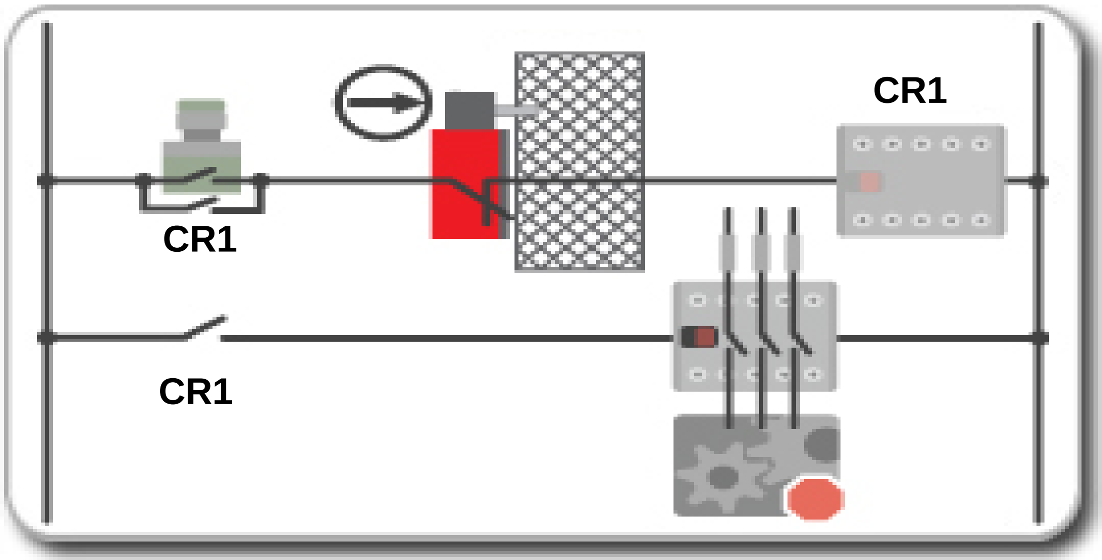
Functional Safety block diagram



- Each circuit has these three elements of either :
  - Individual components
  - Sub-systems of groups of individual devices
  - Encapsulated sub-systems which perform the three functions and may serve as any of the three blocks
- A failure to danger in any block in the series safety block diagram, can lead to the loss of the safety function
  - To evaluate safety performance, each proposed SRP/CS must be broken into a block diagram of Safety Failure Events
  - Note: this includes the interconnection of the blocks
    - Networks, even wires, have their own failure modes

C&E ADVANCED TECHNOLOGIES

What does the “category’s” structure look like?



Cat B & Cat 1 = Single Channel

Cat B = also often called “Simple”

Single failure to danger leads to the loss of the safety function

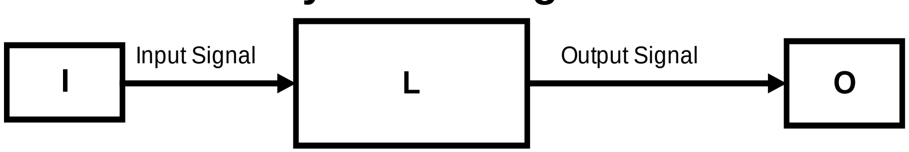
Cat 1 uses “Better Stuff”,

“Well Tried Components” with a history of acceptable performance in safety applications, typically with longer Mean Time to DANGEROUS Failure ($MTTF_D$), and usually includes some “Safety Rated” devices

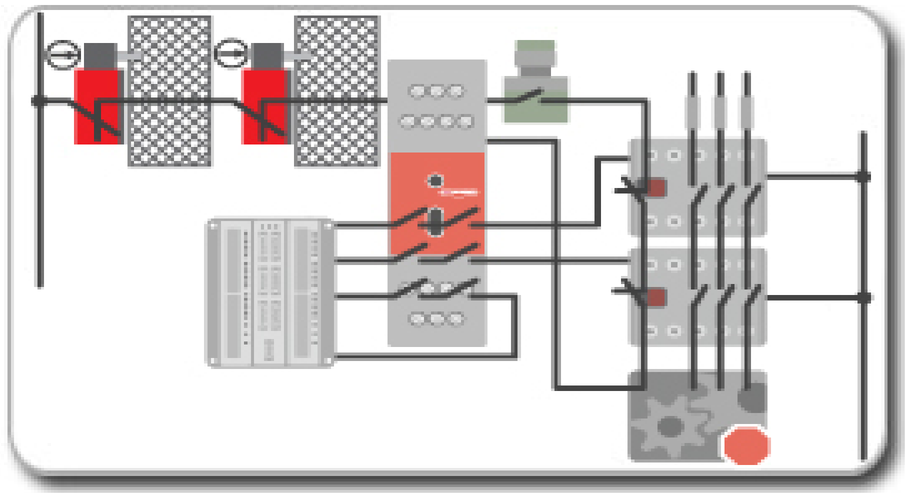
Cat 1

1oo1

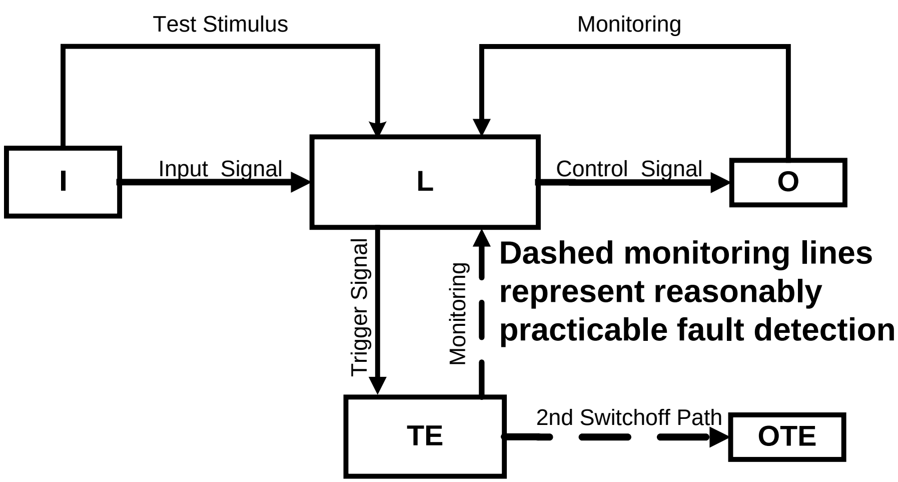
Safety Block Diagram



What does the “category’s” structure look like?



Safety Block Diagram



Cat 2

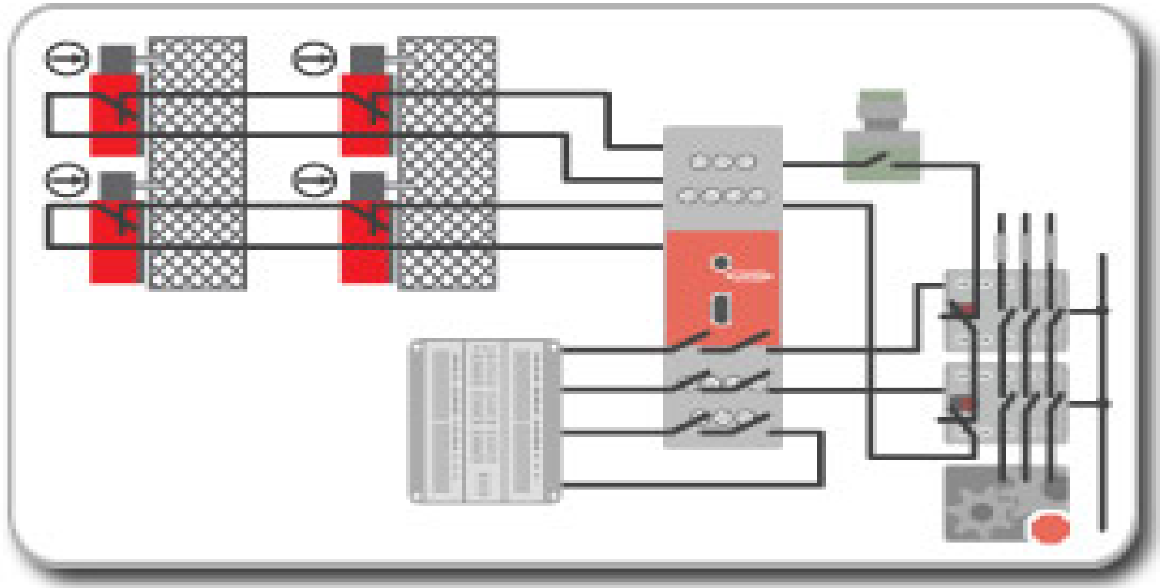
Cat 2 = Single Channel with monitoring for failure to danger

Monitor **at “suitable”** interval ≈ **100x Channel use rate or automatically**

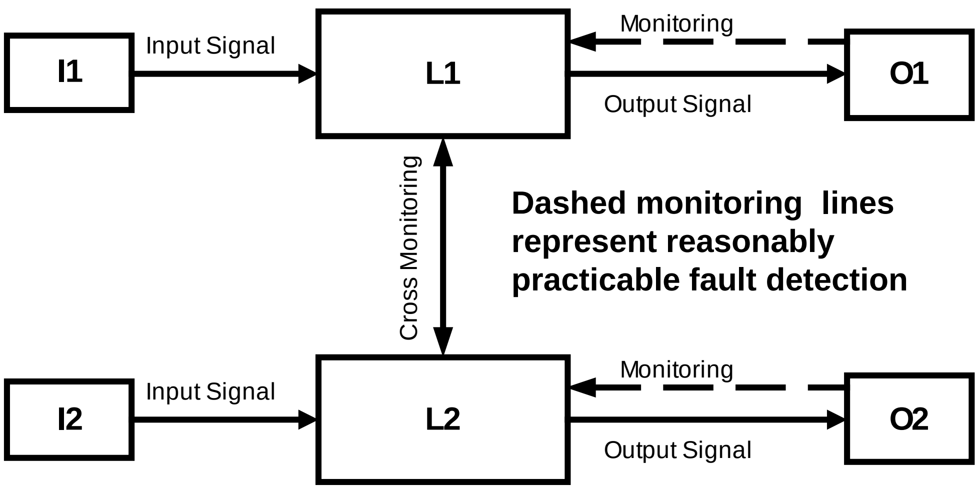
Not all designs are able to shut down the hazard, but may only warn and/or inhibit next hazardous cycle/situation

C&E ADVANCED TECHNOLOGIES

What does the “category’s” structure look like?



Safety Block Diagram



Cat 3

Cat 3 = Dual Channel

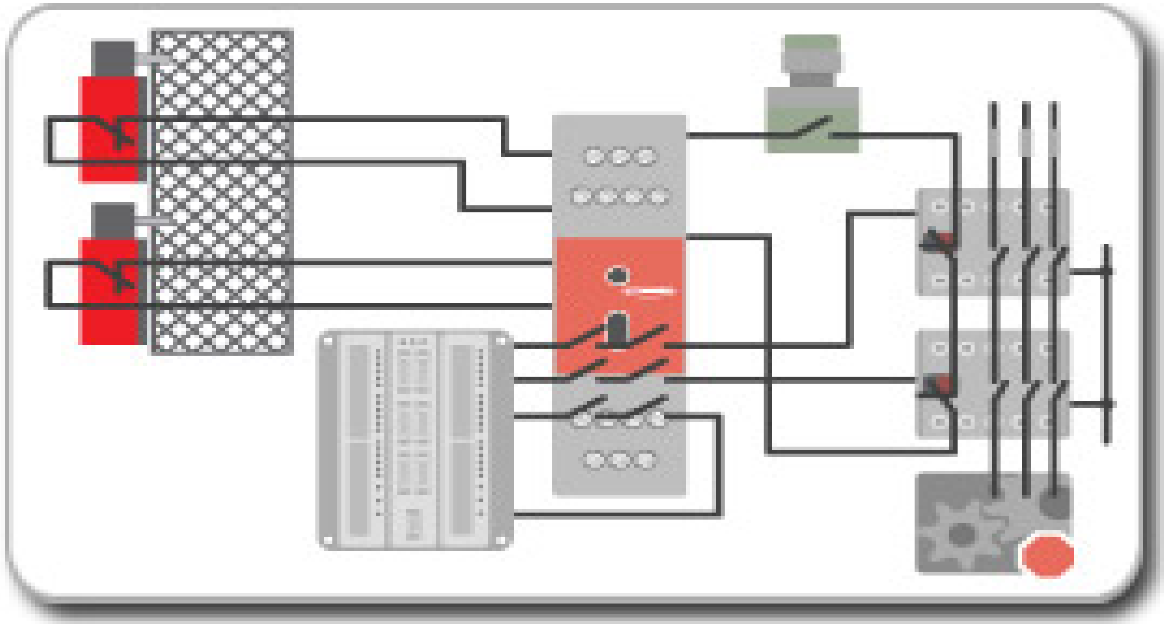
w/ Conditional Monitoring (May not detect all failures to danger)

Single fault will not cause the loss of the safety function

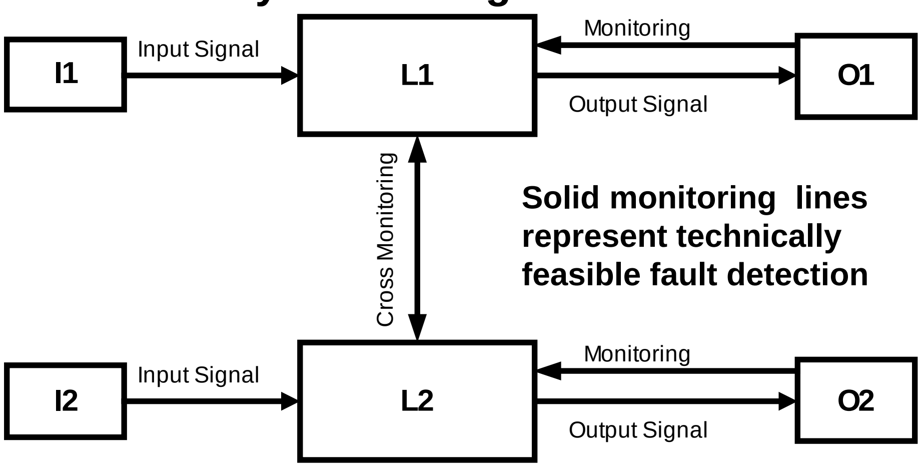
Multiple undetected faults may cause the loss of the safety function

C&E ADVANCED TECHNOLOGIES

What does the “category’s” structure look like?



Safety Block Diagram



Cat 4

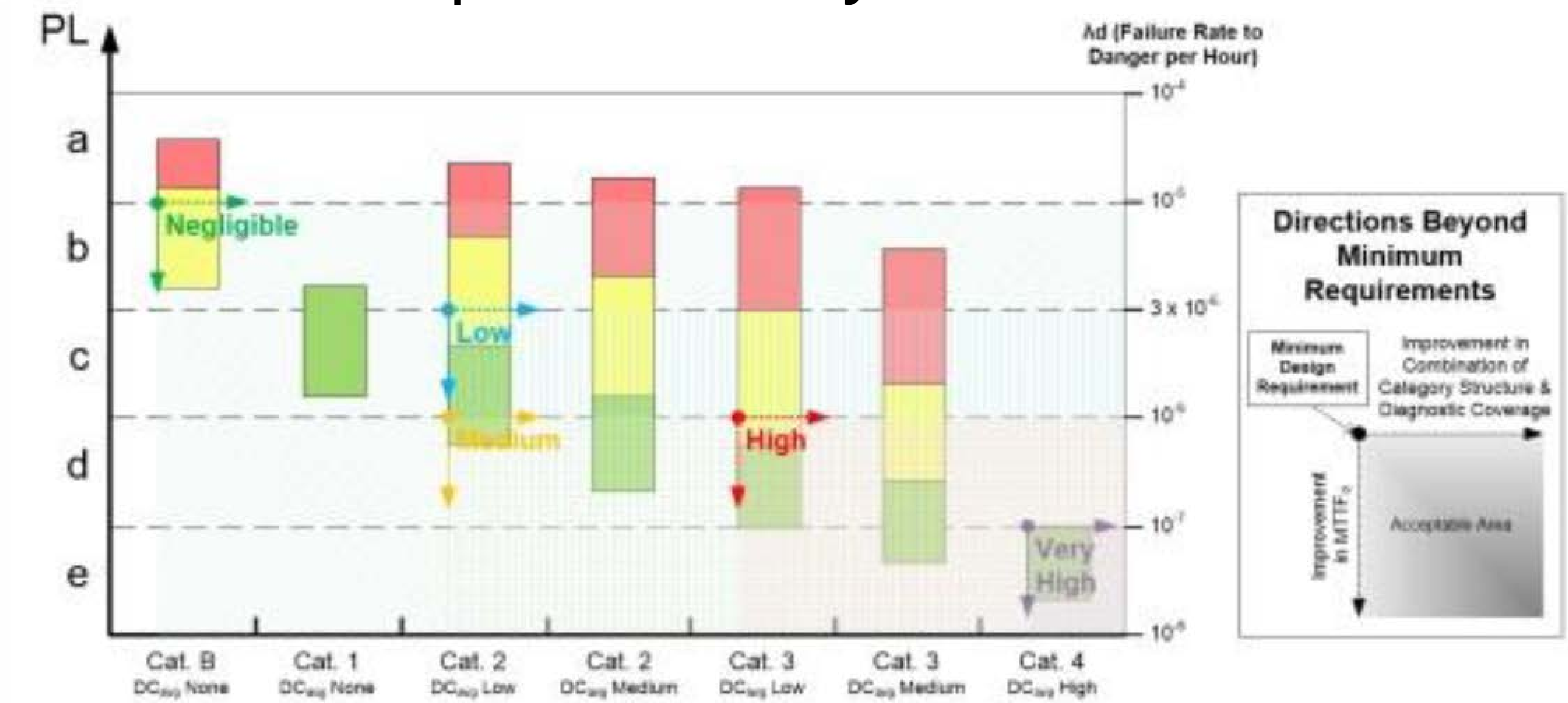
Cat 4 = Dual Channel

w/ Complete Monitoring

Faults to danger of components will not cause the loss of the safety function

Must detect first fault or continue to protect with this and the next fault, this combination must be detected

Performance Level of Safety Function requirements by Risk Level



Risk Levels

- Negligible
- Low
- Medium
- High
- Very High

Mean Time to Dangerous Failure of Each Channel ($MTTF_d$)

	Range of Each Channel
$MTTF_d$ – Low	3 years ≤ $MTTF_d$ < 10 years
$MTTF_d$ – Medium	10 years ≤ $MTTF_d$ < 30 years
$MTTF_d$ – High	30 years ≤ $MTTF_d$ < 100 years

Diagnostic Coverage (DC)

Denotation	Range
None	DC < 60%
Low	60% ≤ DC < 90%
Medium	90% ≤ DC < 99%
High	99% ≤ DC

C&E ADVANCED TECHNOLOGIES

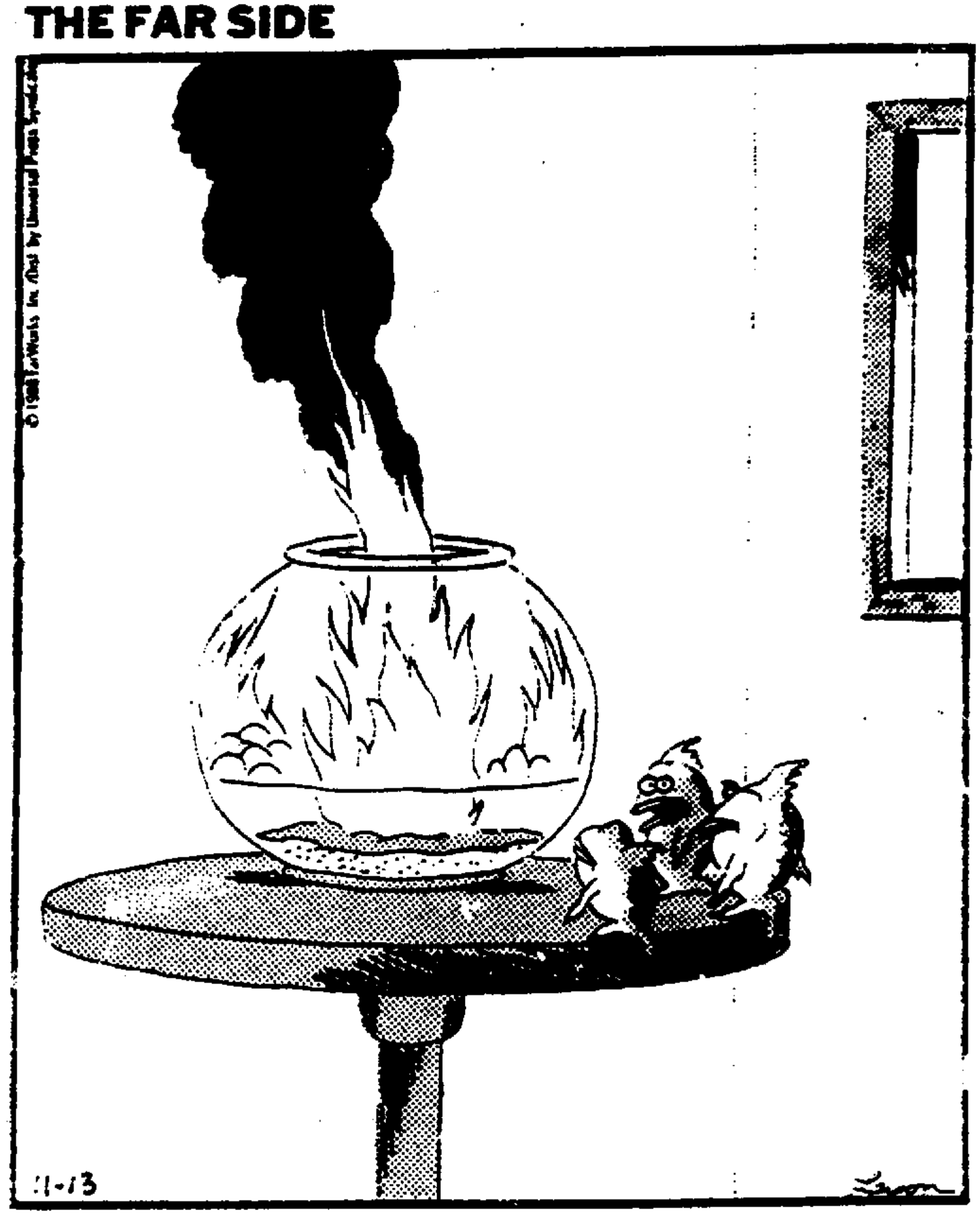
ANSI/RIA TR R15.306-2016 Annex B

Verification

- Re-estimate Task/Hazard pair's risk with the <u>proposed</u> Risk Reduction Measures assumed to be in place
  - Use the same risk estimation process as before to determine :
    - Does the design or process change result in an acceptable level of risk
    - Do any new hazards or task/hazard pairs, which were introduced by the change, result in acceptable risk
    - Is the Safety Function System's performance level appropriate for level of risk to be reduced
      - ⇨ Acceptable Residual Risk **<u>may not be claimed</u>** if the proposed Safety Function does not meet or exceed the minimum performance level requirement for the level of risk as determined by the Risk Assessment
    - Does measure meet Human and Environmental needs
    - Does measure meet operational requirements, is sustainable, and will be used

Engineering Compromise
_Or_
Does my "risk reduction measure" have a FLAW?

A NEW hazard brought on by the "solution"



"Well, thank God we all made it out in time. . . . 'Course, now we're equally screwed."

C&E ADVANCED TECHNOLOGIES

Residual Risk

- With the proposed risk reduction measures implemented, will the level of risk then be acceptable ?
  - If No
    - Reduce risk from existing or new task/hazard pair(s) with more effective or additional risk reduction measures by repeating the process
  - If Yes
    - Identify remaining residual risks
    - Further reduce these by developing procedures, operating instructions, and training

Implementation and Validation

- Develop Implementation Plan and time table
- Write Validation Plan for each Safety Function, which contains:
  - Functional tests to be performed
    - Operation of the safety function as specified in the R.A.
    - Induce failure modes
    - Include reasonably foreseeable misuse
  - Safe test procedure for each individual test
  - Correct performance of the safety function control
    - Risk reduction functions as described in Plan
    - Auxiliary equipment achieves safe state as required
- Identify any systematic software and logical errors or omissions
- Document the validation test results

Monitor Safety Performance

- Monitor the Machine and its Risk Reduction Measures for:
  - Accident rate
    - Including close calls and near misses
  - Utilization
  - Ability to maintain

C&E ADVANCED TECHNOLOGIES

A Risk Assessment Example

- The machine
  - Hand load cylinder tube and bracket onto a fixture with automatic clamps
  - Robotic MIG weld bracket to tube

Identify the Tasks

- Operation/production
  - Weld top mounting bracket on strut reservoir
    - Auto mode
      - Load bracket and strut reservoir tube
    - Manual mode
      - Set-up and changeover
      - Movement or replenishment of process material
      - Replace weld wire, dress weld tip
      - Interventions
        - » wire jams, bad material, bad clamp position
    - Maintenance
      - Trouble shooting
        - » Especially those tasks which may require power to accomplish

C&E ADVANCED TECHNOLOGIES

Machine: Strut Welder
Date: 1 Apr 2010
Proj. Mgr: A.E.Newman
Loc: Plt. II EZ-27

Risk Assessment Work Sheet

No	Task Description	Hazards	S	E	A	RL	Solution	S	E	A	RL/PL
		NON Reduced Risk	Before Safeguarding				Residual Risk: Only risk reduction measures which directly impact S,E,A i.e. Design & Process are re-evaluated	After Safeguarding			
1.1	Tip change	Struck by Robot	3	2	2	HI	Interlock gate with safety key lock to drop servo power to robot	3	2	2	3/PLd
1.2	Tip change	Pinch by end effector	2	2	2	HI	Interlock gate with safety key lock to drop servo power to robot	2	2	2	3/PLd
1.3	Tip change	Hot Surface	2	2	1	MED	Limit Temp w/ cooling system PPE Thermal Protective Gloves	1	1	1	2/PLc
2.1	Replace Weld Wire	Struck by Robot	3	1	2	HI	Interlock gate with safety key lock to drop servo power to robot	3	1	2	3/PLd
2.2	Replace Weld Wire	Pinch by end effector	2	1	2	MED	Interlock gate with safety key lock to drop servo power to robot	2	1	2	2/PLd
2.6	Replace Weld Wire	Fall from height	2	1	1	MED	Lower spool axis, Provide robot low park position	1	1	1	NEG
2.7	Replace Weld Wire	Back injury	2	2	1	MED	Provide robot low park position or hoist Use floor pallet and wire de-reel fixture	1	2	1	LO
3.1	Load Fixture	Struck by Robot	2	2	2	HI	Safety Light Curtain to drop servo power to robot	2	2	2	3/PLd
3.4	Load Fixture	Trap by end effector	2	2	2	HI	Safety Light Curtain to drop servo power to robot	2	2	2	3/PLd
3.5	Load Fixture	Trap by Clamp tools	1	2	1	LO	Safety Light Curtain to drop power to clamp solenoid valves	1	2	1	2/PLc

EXAMPLE

Note: If a task is not *accomplished during normal production operations, and is not Routine, Repetitive, and Integral to the use of the equipment for Production* it is considered by OSHA to be Maintenance vs.. Operator Operational activity. It is still listed here . The risk reduction measure is either *NORMAL LOCK-OUT TAG-OUT PROCEDURES* or ALTERNATE RISK REDUCTION MEASURE (OSHA sub Part O) if LOTO is not practicable

Ref: CFR 29 1910.147(a) (2) (i) and (ii) See also ANSI Z244.1 LOTO and Alternate Safeguarding

Overview of collaborative robots

- Data in this presentation is derived from ANSI/RIA TR R15.606 Collaborative Robots
  - A United States adoption of ISO/TS 15066
  - A **T**echnical **S**pecification:
    - Is not a standard but is the preliminary publication of data, which with further refinement and testing, is intended to be included in a published Standard (no TS in USA)
    - Represents industry best practice at the time of publication
    - It carries more weight than a Technical Report (TR) which generally is a further explanation of the intent and application of a published standard, which has no mandatory requirements
    - Uses standards terms such as "shall" to indicate a normative, mandatory requirement, which is typically avoided in a TR
  - Applied in conjunction with ANSI/RIA 15.06 Industrial Robot and Robot Systems- Safety Requirements

Collaborative Robot Application

Collaborative Robots

- Goal of Collaborative systems: Combine the repetitive performance of robots with the individual skills and problem solving ability of individuals, through direct interaction within a defined collaborative workspace
  - Traditionally, individuals have been excluded from the industrial robot system's maximum/restricted space while the robot is active
- Collaborative workspace: a space within the robot operating space where the **robot system** may perform a task concurrently with an individual, during a production operation.
  - By definition, a robot does not include an end effector or piece part, both of which are added by the user as part of the robot system

Collaborative Robots

- Implementation of a collaborative robot requires a comprehensive risk assessment of:
  - The tasks of both
    - The individual
    - The robot ***SYSTEM***
      - Robot, end effector, workpiece, direct support equipment
  - Environment of the collaborative workspace in which they operate
    - Material handling
    - Secondary operations equipment
    - Non associated machines and equipment
    - Structures

C&E ADVANCED TECHNOLOGIES

Collaborative Applications

- The out of the box “safe” robot **system** is a myth
  - A robot is “partially completed machinery” which may have physical characteristics and safety-rated controls which make it a viable candidate for collaborative application

Collaborative Application

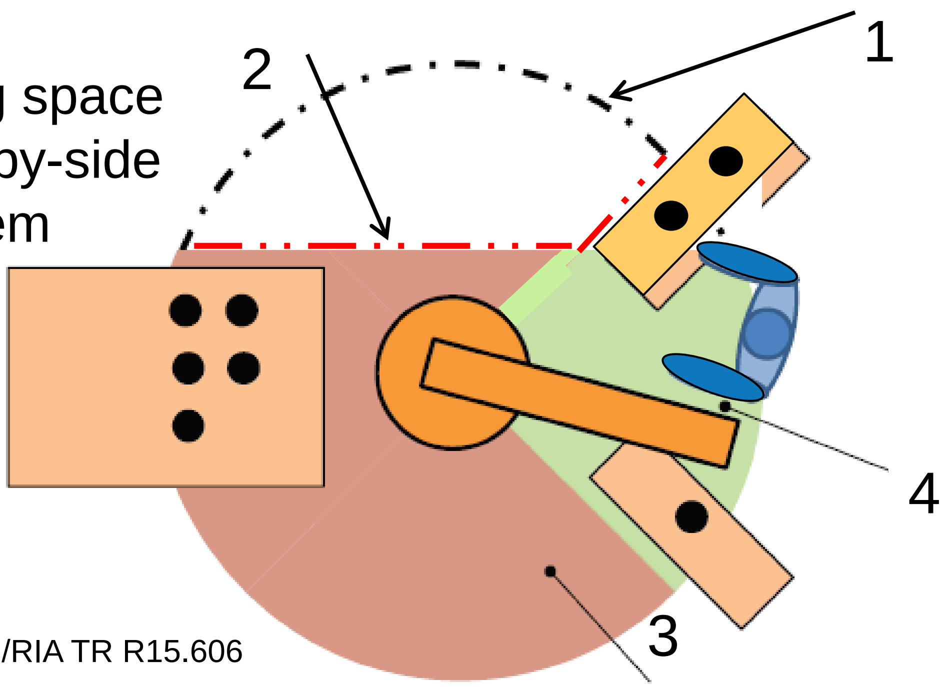
- **It is not only the robot itself** which determines if the application may be collaborative with a reasonable risk
  – *Robot manufacturer can only define the safety performance of the robot, not the conditions under which it will ultimately be used*
- **<u>It is the application</u>,** the entire task of the individual and robot system, manufacturing process, and ancillary equipment, which determine if a collaborative application can be achieved with an acceptable level of risk
- Under the correct application conditions, and with built-in or add-on external safety-rated risk reduction controls and measures, any given robot might be capable of collaborative operation for a <u>specific application</u>

Two types of risk reduction approach for Robotic applications

- Traditional Industrial robot applications
  - Risk reduction measures separate the individual from the active robot
  - No contact or shared workspace with the robot
- Collaborative robot applications consist of:
  - Robot System and individual(s) occupying the same workspace
  - Collaborative workspace which contains
    - Portion of the robot system operating space
    - Direct support equipment, including manual operation
    - Other machines or equipment
    - Physical obstructions

Four types of space may be involved, risk reduction measures for each must be identified in the risk assessment

1. Maximum space which an unrestricted robot system can reach
2. Restricted space
   - Robot system mobility area from which it cannot exit
3. Operating space
   - Where the robot may work autonomously
   - Is **not** part of the collaborative workspace,
   - Risk reduction measures here are traditional / non-collaborative
4. Collaborative workspace
   - Specific part of the operating space
   - Individual(s) may work side-by-side with an operating robot system
   - Collaborative risk reduction measures



Key

1 Maximum Workspace
2 Restricted Space Boundary
3 Operating Space
4 Collaborative Workspace

Adapted from ANSI/RIA TR R15.606

Risk reduction Strategies for Collaborative Applications

- Robot and individual(s) may occupy the collaborative workspace at the same time
- Types of operating mode:
  - No contact between a MOVING robot system and an individual
  - Robot system is guided by the individual
  - Concurrent movement of individual and robot system
    - Robot actively avoids moving contact with individual

      OR
    - Anticipate occasional contact events of individual(s) with moving robot system
      - The energy and force available to the robot system is limited to such a value that any reasonably foreseeable contact will not produce pain or injury

C&E ADVANCED TECHNOLOGIES

Risk Reduction Strategies for Collaborative Applications

- For collaborative robot applications, a risk assessment must be completed <u>during the project development</u> to identify all risks, and risk reduction strategies
  - Particularly those risks due to the close proximity of robot system and individuals
- Elements of risk of a collaborative application
  - Tasks of both individual and robot system
  - Robot system
  - Environment of the collaborative workspace
- Determine if a collaborative robot application with acceptable risk is practicable

Risk reduction Strategies for Collaborative Applications

- Determine how the robot system related risks can be reduced to an acceptable level by implementing a combination of :
  - Robot collaborative operation risk reduction strategies
  - Conventional risk reduction measures
- The risk assessment establishes the task’s capability, and possible limitations, of a practicable collaborative application
  - Operational functions of the task
  - Operational and physical limitations of the robot
    - Including special robot functions, typically safety rated

Definitions as used in ANSI/RIA TR R15.606

- Safety-rated monitored stop
  - Stop initiated under "normal" collaborative operating conditions
  - Retains power on each robot drive axis (NFPA Stop Cat 2)
    - Prevents motion by controlling axis motor's rotating field
  - Performance Level PLd structure Category 3
  - May resume collaborative operation when stop conditions clear
- Safety-rated monitored protective stop
  - Stop initiated under "abnormal" collaborative operating conditions, to avoid a hazardous situation
  - Removes power from each robot motor drive axis (NFPA Stop Cat 0,1)
    - Prevents motion by engaging axis brake(s), counter balance, mechanical advantage
  - Performance Level PLd structure Category 3
  - Requires manual reset from outside of collaborative workspace

Risk reduction Strategies for Collaborative Applications

- Four types of collaborative operation
  - First three prevent contact with the operating robot system
    - Safety-rated Monitored Stop
    - Hand Guiding
    - Safety-rated Speed and Separation Monitoring
    - Power and Force Limiting

C&E ADVANCED TECHNOLOGIES

Safety-Rated Monitored Stop

- Robot operates autonomously within the collaborative workspace when no individual is present
- Robot executes a safety-rated monitored stop at the end of a task, or when an individual enters the collaborative workspace
- Resumes autonomous operation when collaborative workspace is clear of individuals
- If the robot moves while an individual is in the collaborative workspace, a safety-rated monitored protective stop is initiated
  - Requires a manual reset to resume collaborative operation
  - Reset device to located outside of the collaborative workspace

Hand Guiding

- Robot may be operating autonomously in collaborative workspace when no individual is in the workspace
- Robot executes a safety-rated monitored stop at end of task, before individual enters collaborative workspace
- Operator hand guides robot arm with safety-rated monitored hand guiding device, with enabling device, to control robot motion
  - Releasing hand guide, executes a safety-rated monitored stop
- Robot may resume autonomous operation when collaborative workspace is clear of individuals
- If individuals enter collaborative workspace when robot is not in safety-rated monitored stop, executes a safety-rated monitored protective stop
  - Requires a manual reset to enable collaborative operation
  - Reset device is located outside of the collaborative workspace

Safety-rated Speed and Separation Monitoring

- Robot and individual(s) may move concurrently in the collaborative workspace
- Operating under a safety-rated monitored speed function, the robot maintains at least a safe separation distance from an individual(s) in the collaborative workspace
  - Separation distance may vary with robot speed
  - Robot speed may vary with separation distance
- Resumes collaborative operation from a Safety-rated monitored stop when safety separation distance is reestablished
- Unless Robot is in safety-rated monitored stop, executes a safety-rated monitored protective stop if individual is within safety separation distance
  - Requires a manual reset to resume collaborative operation
  - Reset device to located outside of the collaborative workspace

Power and Force Limiting

- Robot (often referred to as a COBOT) and individual may move concurrently within the collaborative workspace
- The robot **system** may come into direct contact with an individual either intentionally or accidentally (the contact event)
- PFL is the only collaborative operation in which physical contact between moving robot and individual may be allowed
- Power and Force is limited, so that robot system's physical contact with an individual **in the collaborative workspace** will not result in pain or injury

C&E ADVANCED TECHNOLOGIES

Power and Force Limiting

- The contact event
  - Quasi-static contact (clamping, crushing, or trapping)
    - Will experience both initial impact and continued pressure
    - Includes contact pressure hazard from structure “behind” the body part under pressure of the robot system
  - Transient (Dynamic), individual’s contact area able to rebound from contact (impact) event
    - Pressure during the first 0.5 seconds of the contact event
    - ☆ Impact and rebound may propel individual into other structure

Power and Force Limiting

- Risk assessment must be completed in the design development stage to determine if the application can successfully be made PFL
  - Robot System mass and speed determine energy available at the contact event
    - Sum of Mass of moving robot, end effector, and workpiece
    - Robot operation (arm and workpiece speed (TCP) and travel distance)
  - Pressure exerted on the body part by force available
    - Size of contact area determines pressure developed
      - Shape of end effector, rigid workpiece, and support equipment
        - » Ex: edges, sharp corners, or projections

Two types of contact event

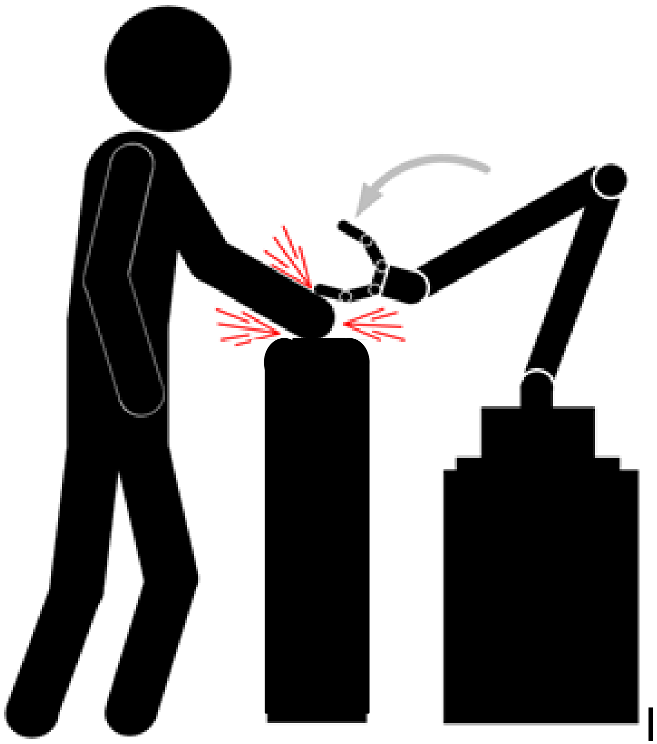


Figure 6: Quasi-static contact event

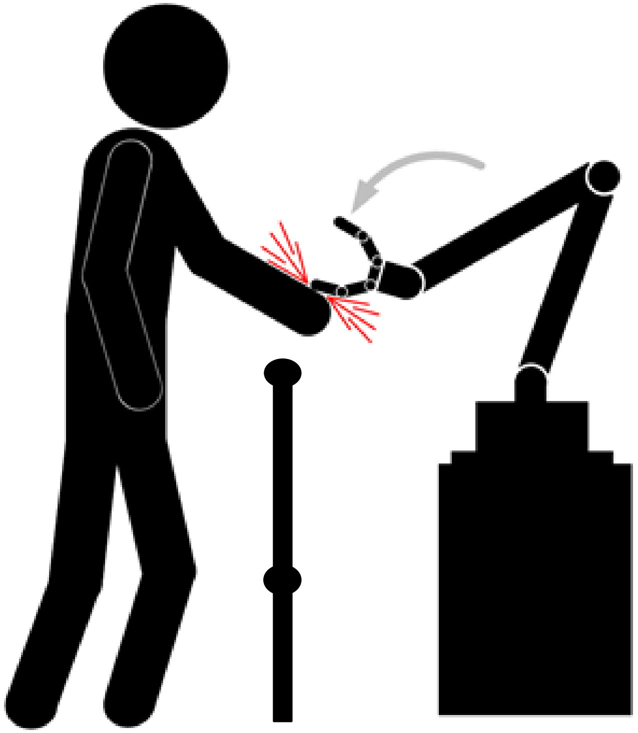
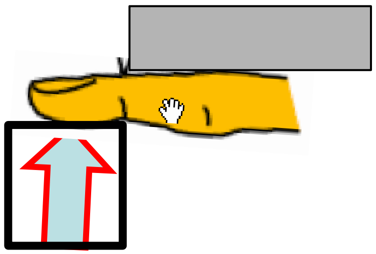


Figure 7: Transient contact event

Effect of object "behind" body part at point of contact, of what otherwise might be an acceptable contact event



An object in the rebound path or if the robot continues its path after the transient contact, a second contact event may occur

Adapted from ANSI/RIA TR R15.806

Power and Force Limiting

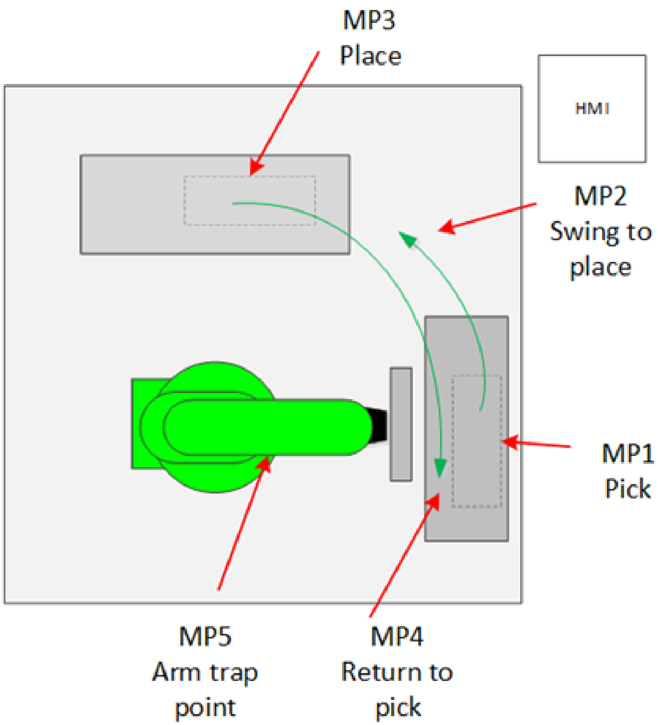
- Allowable force/energy limits vary by:
  - Type of contact event
  - Location of contact event on the body
    - Areas on which contact must be avoided
    - Mass of the body part
    - Body characteristics of :
      - » Spring constant
      - » Damping property
      - » Skin thickness
    - Pressure limits for onset of pain

Power and Force Limiting

- Ability to anticipate/predict contact events vary by type of interaction between individual and robot
  - ☆ Fully coordinated defined task
  - Intervention on an exception basis
  - Proximity to autonomous operation
    - Accidental contact event, typically initiated by the individual

Risk Assessment Detail for Power and Free application

- Identify all reasonably foreseeable contact events
  - Type of contact for each robot system motion which can result in a contact event
  - Worst case body part area of contact for each contact event



ANSI/RIA TR R15.806 Fig2

C&E ADVANCED TECHNOLOGIES

Typical Cobot PFL Characteristics

- Force limited
  - Robot Arm
- Low kinetic energy
  - Slow combined speed due to all moving axis
  - Low mass robot arm of moving axis
  - Low Load limit
    - Combined mass of end effector & work piece ≤10kg/22lb
  - Short reach ≤1300mm/51in
- Energy transfer of contact limited by speed and force control
  - Inherently safe design
    - Limiting system maximums by fixed robot design
  - Multiple **safety-rated** monitored features PLr ≥ PLd Cat 3
    - Stop
    - Programmed Speed and Force (Torque)
    - Force Sensing (Collision Detection, w/wo motion reversal)
    - Space Limiting (restricted space) range of motion
  - Features are typically options, to be specified at initial purchase

Typical Cobot PFL Characteristics

- Passive safe physical design
  - No shear or pinch points
  - Rounded members
    - No sharp corners or projections
  - Minimum blind holes or openings
    - Diameter < 6mm dia.
  - Soft covering or skin
    - Could also be force sensing for contact detection
- Easy to program or guide teach to provide flexibility of application

Cobot Application Risk Reduction Measures

- Limit force and energy available upon contact event
  - Contact force and resulting pressure
  - Energy transferred during contact event, are function of speed and mass
    - Keep these values below maximum threshold based on:
      - Type of contact event
      - Body area contacted during the event
- Eliminate corners and projections and small areas of contact with:
  - Covers, housings, separating surfaces
- Eliminate discontinuous surfaces
  - EX: Square tooling plate mounted on wrist

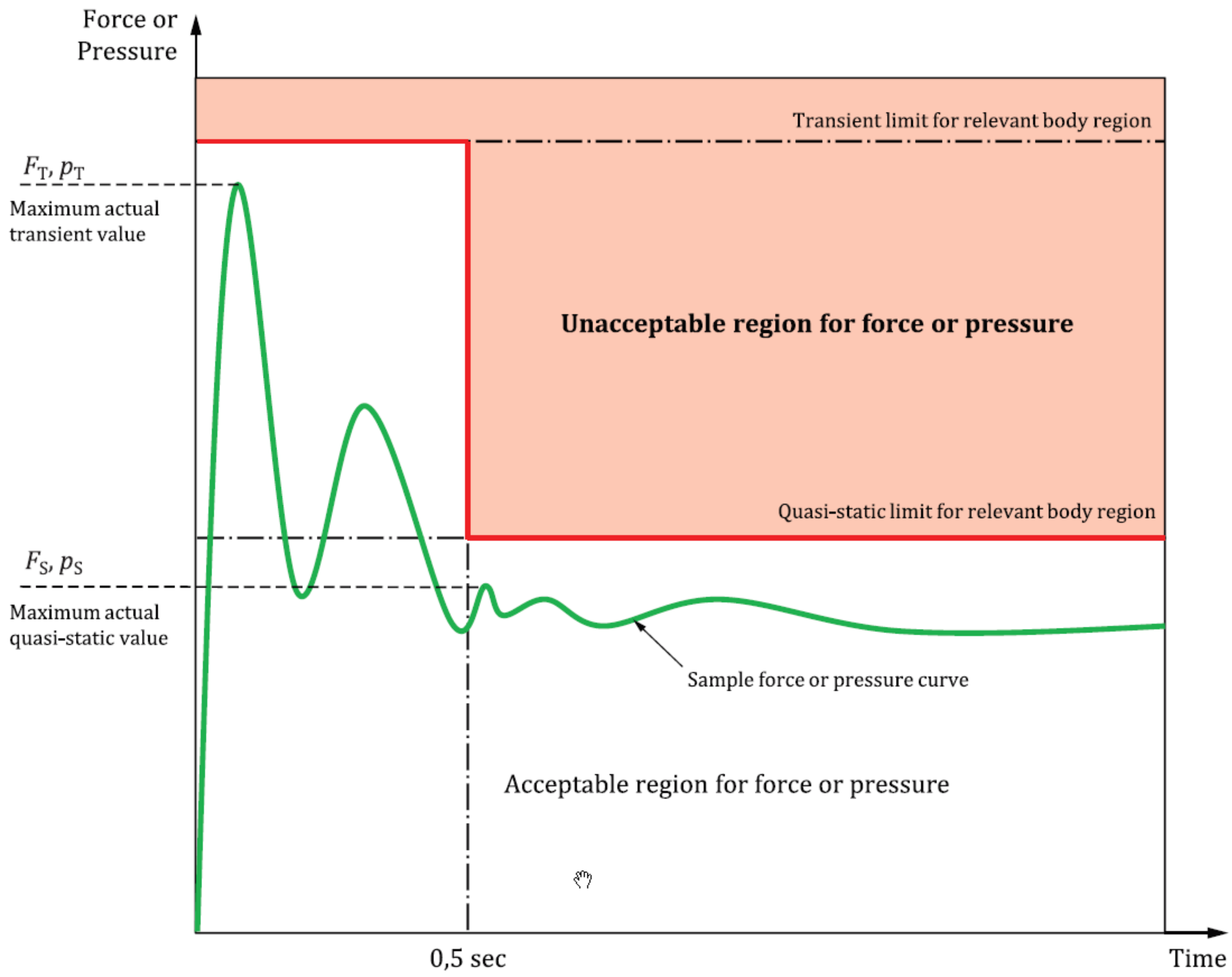
Cobot Application
Risk Reduction Measures

- Design task to reduce the probability of a contact event
- Design robot system and collaborative workspace to minimize contact and maximize avoidance
  - Design task to avoid robot path
  - Minimize robot path contact with individual's work pattern
  - Program robot to avoid sensitive body area using space limiting

Quasi-static
Design guide lines

- Limit force
- Force monitoring with robot travel reverse to limit time under pressure
- Large contact area to reduce pressure
- Provide clearance (20” or more) between robot path and fixed objects to prevent trapping
- Follow Transient contact guidelines to manage initial contact impact

Possible Quasi-static impact force – time graph



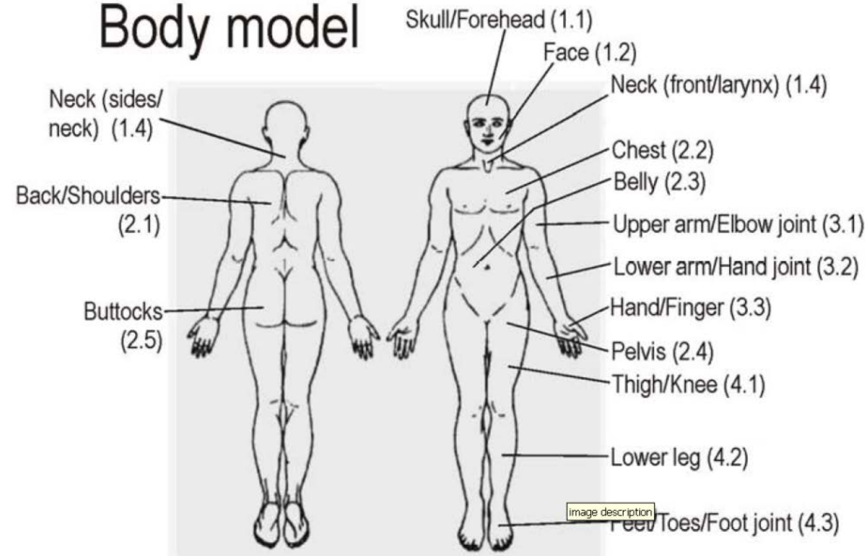
C&E ADVANCED TECHNOLOGIES

Biomechanical Limits of "Pain Onset Level"

ANSI/RIA TR R 15. 606 Table A.2 — Biomechanical limits

Body region		Specific body area	Quasi-static contact: Maximum permissible pressure [a] p_s N/cm^2	Quasi-static contact: Maximum permissible force [b] N	Transient contact: Maximum permissible pressure multiplier [c] P_T	Transient contact: Maximum permissible force multiplier [c] F_T
Skull and forehead [d]	*1*	*Middle of forehead*	*130*	*130*	*not applicable*	*not applicable*
	2	*Temple* **CRITICAL ZONE**	*110*		*not applicable*	
Face [d]	*3*	*Masticatory muscle*	*110*	*65*	*not applicable*	*not applicable*
Neck	4	Neck muscle	140	150	2	2
	5	Seventh neck muscle	210		2	
Back and shoulders	6	Shoulder joint	160	210	2	2
	7	Fifth lumbar vertebra	210		2	2
Chest	8	Sternum	120	140	2	2
	9	Pectoral muscle	170		2	
Abdomen	10	Abdominal muscle	140	110	2	2
Pelvis	11	Pelvic bone	210	180	2	2
Upper arms and elbow joints	12	Deltoid muscle	190	150	2	2
	13	Humerus	220		2	
Lower arms and wrist joints	14	Radial bone	190	160	2	2
	15	Forearm muscle	180		2	
	16	Arm nerve	180		2	
Hands and fingers	17	Forefinger pad D	300	140	2	2
	18	Forefinger pad ND	270		2	
	19	Forefinger end joint D	280		2	
	20	Forefinger end joint ND	220		2	
	21	Thenar eminence	200		2	
	22	Palm D	260		2	
	23	Palm ND	260		2	
	24	Back of the hand D	200		2	
	25	Back of the hand ND	190		2	
Thighs and knees	26	Thigh muscle	250	220	2	2
	27	Kneecap	220		2	
Lower legs	28	Middle of shin	220	130	2	2
	29	Calf muscle	210		2	

Body model



NIST Collaborative Robotics: Measuring Blunt Force Impacts on Humans

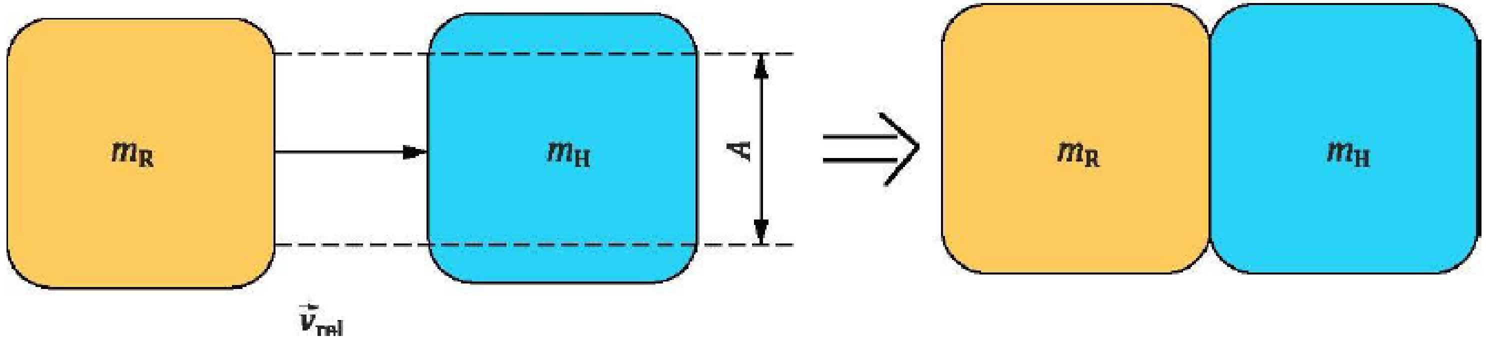
1lb=4.5 Newton 1in^2 = 6.5 cm^2 N/cm^2 =1.5 lb./in^2

Transient Impact
Design guide lines

- Keep mass and speed low
  - Safety-rated maximum speed
- Safety-rated force monitoring
- Keep contact area large
- Avoid sharp corners and projections on other objects onto which the individual might be propelled
- Manage results after impact
  - Distance of system reach and force detection reversal to prevent transient impact from becoming Quasi-static

Transient Impact

- Each body part has a maximum transferred energy limit pain threshold
- Energy transferred is a function of
  - Robot system mass
  - Relative travel speeds and directions of robot and body region
  - Mass and spring constant of the body at the area of contact
  - Size of the contact area

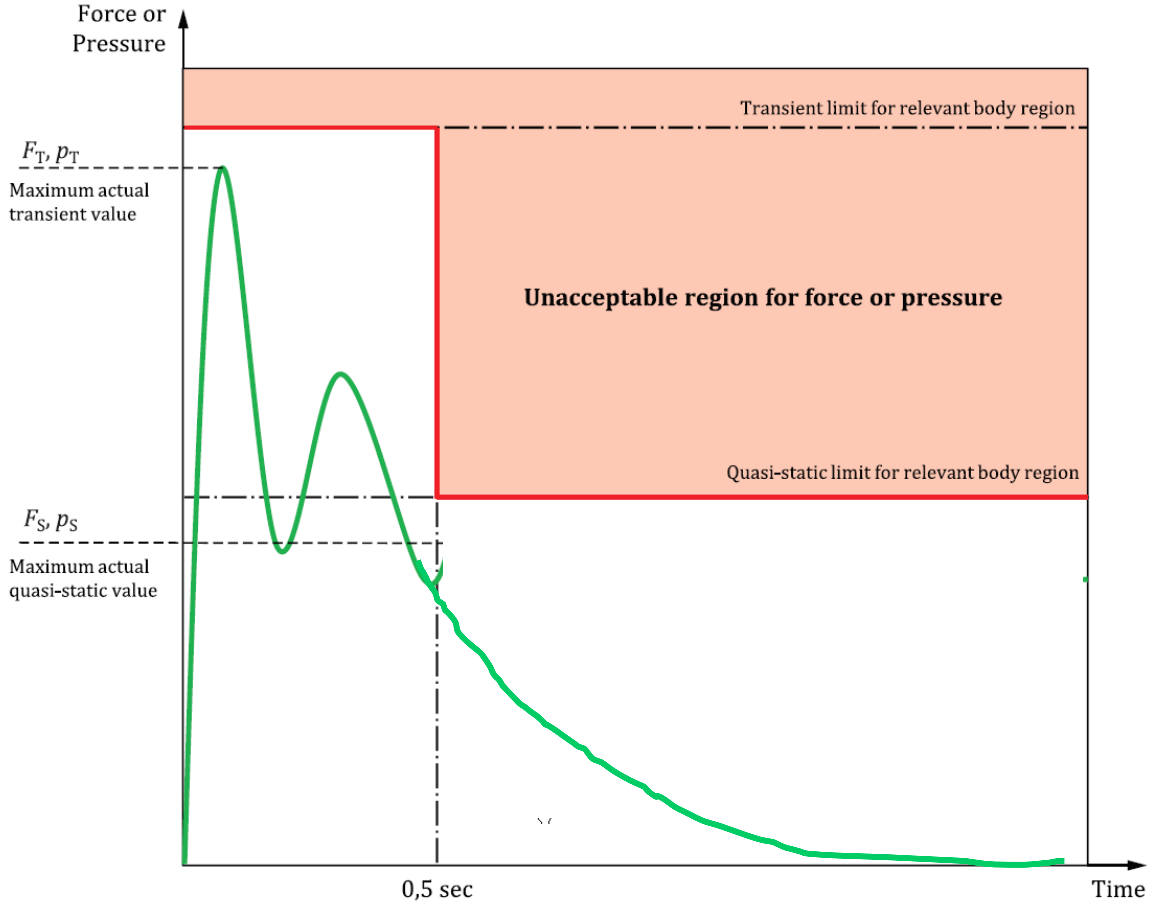


Key

A	area of contact between robot and body region
m_H	effective mass of human body region
m_R	effective mass of robot as a function of robot posture and motion
v_{rel}	relative speed between robot and human body region

ANSI/RIA TR R15.606 **Figure A.2 — Contact model for transient contact**

Possible Transient force – time graph



C&E ADVANCED TECHNOLOGIES

Transient Impact

Table A.3 — Effective masses and spring constants for the body model

Body region	Effective spring constant *K* N/mm	Effective mass m_H kg
Skull and forehead	150	4.4
Face	75	4.4
Neck	50	1.2
Back and shoulders	35	40
Chest	25	40
Abdomen	10	40
Pelvis	25	40
Upper arms and elbow joints	30	3
Lower arms and wrist joints	40	2
Hands and fingers	75	0.6
Thighs and knees	50	
Lower legs	60	

NOTE Mass values for thighs, knees and lower legs are set to the full body weight, recoil or retract from impact while the operator is standing.

For each body region, the maximum permissible energy transfer can be maximum force or maximum pressure values shown in Table A.2 using l

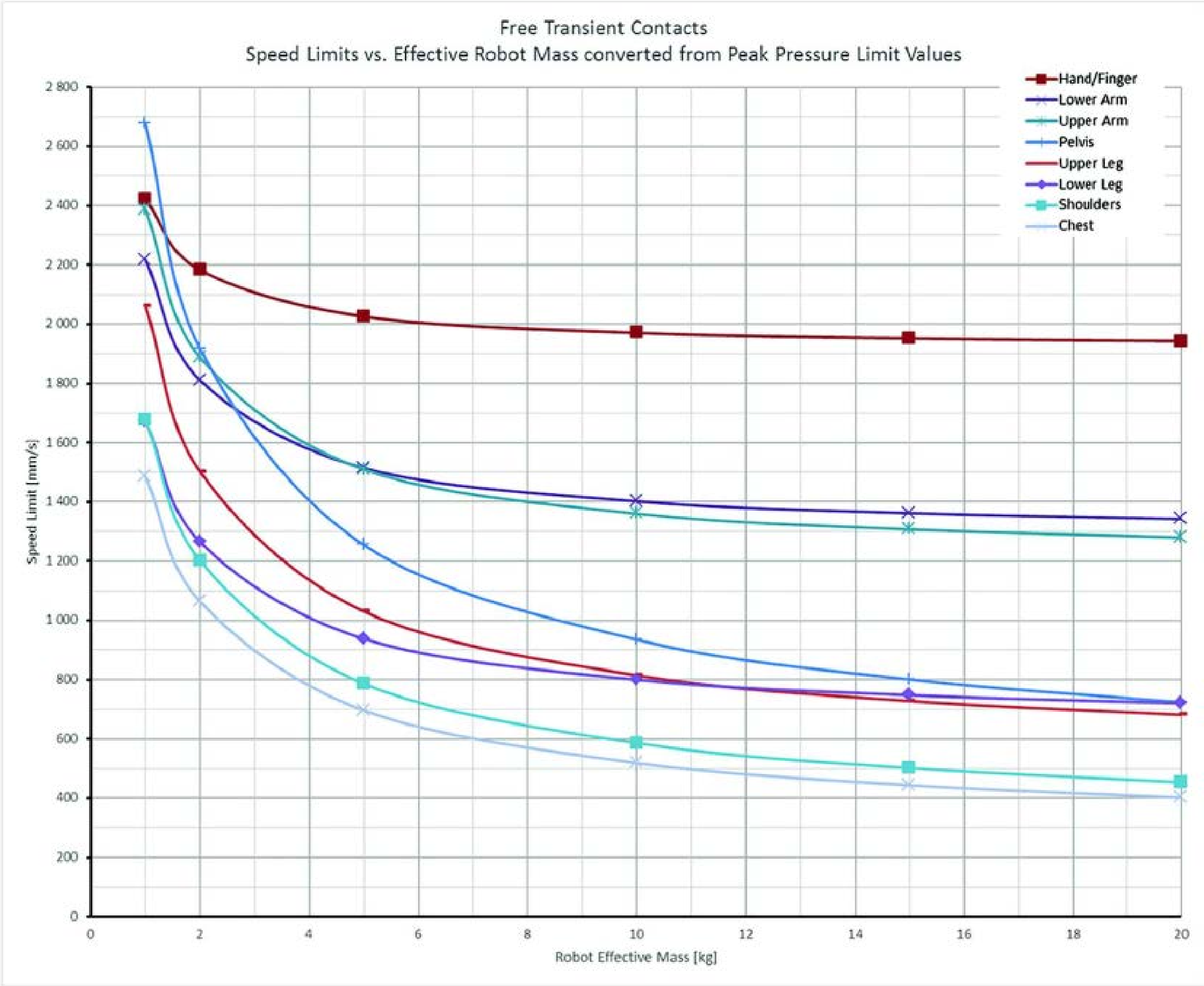
Table A.4 — Energy limit values based on the body region model

Body region	Maximum transferred energy *E* J
Skull and forehead	0.23
Face	0.11
Neck	0.84
Back and shoulders	2.5
Chest	1.6
Abdomen	2.4
Pelvis	2.6
Upper arms and elbow joints	1.5
Lower arms and wrist joints	1.3
Hands and fingers	0.49
Thighs and knees	1.9
Lower legs	0.52

ANSI/RIA TR R15.606

C&E ADVANCED TECHNOLOGIES

Graph of maximum speed of a 1cm^2 contact event for a given robot system mass at a specific body part

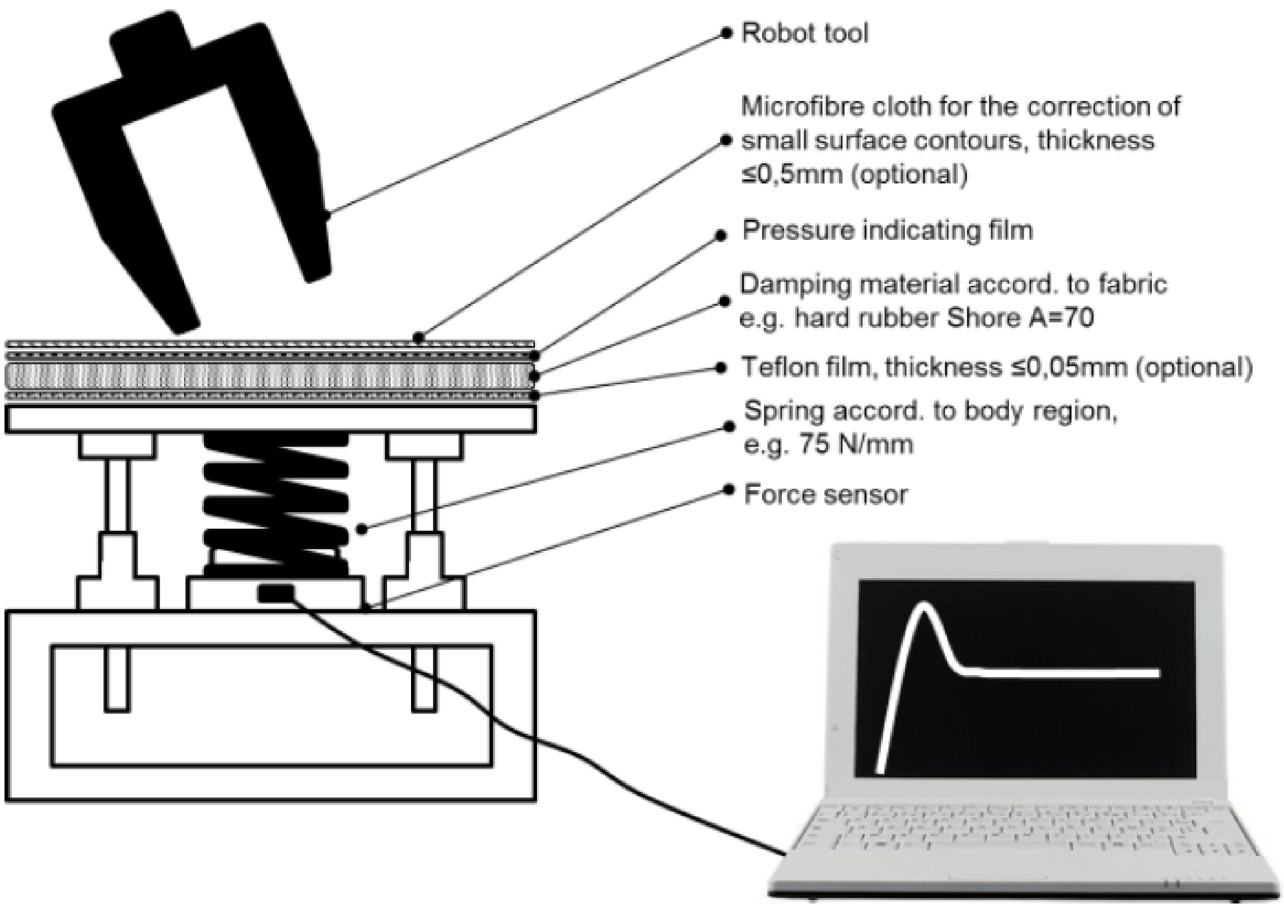


ANSI/RIA TR R15.606 Figure A.4 Graphical representation of calculated speed limit based on the body model

Validation

- The application must be validated by physical measurement testing to assure that the predicted forces and pressures do not exceed the permissible limits
  - Requires specialized equipment and training
  - Testing must be documented
    - Method and equipment used
    - Test results

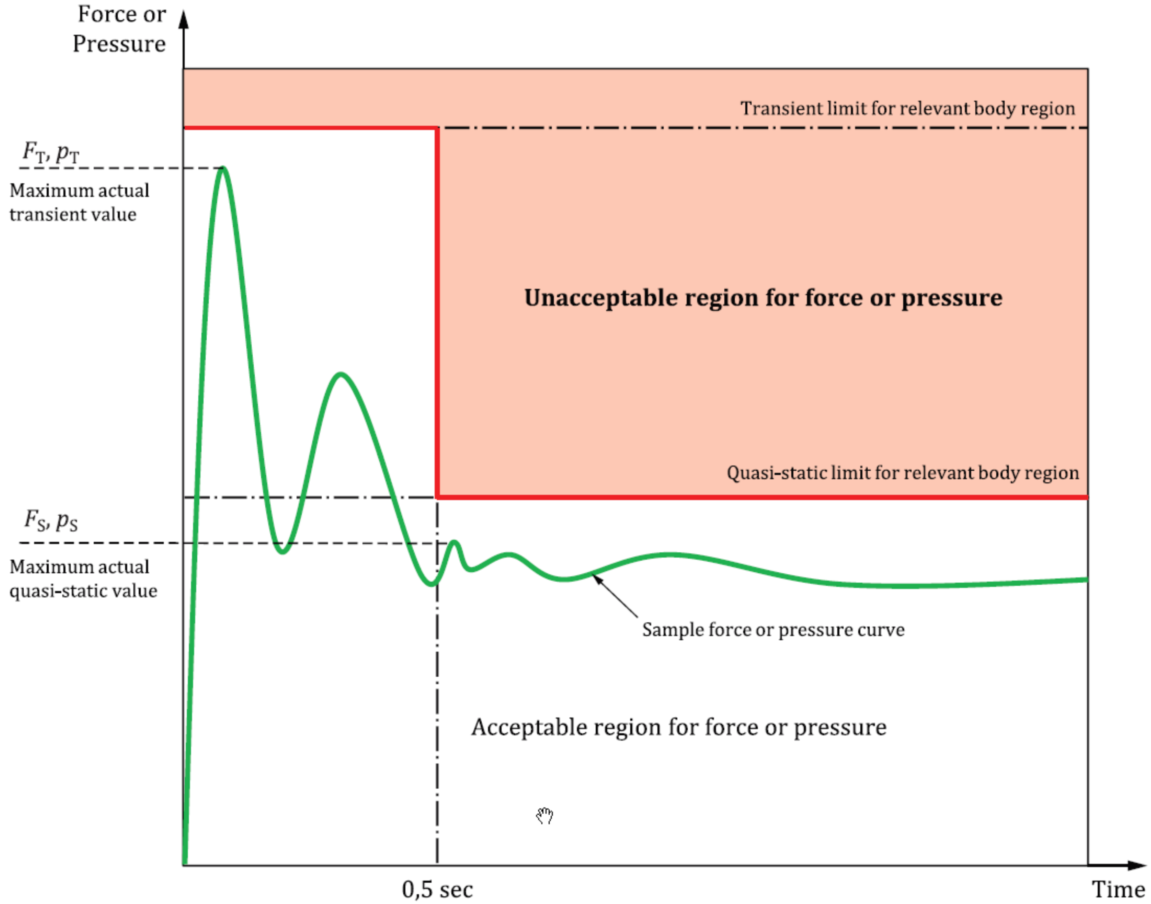
Measuring force and pressure



DGUV –Information FB HM-080 8/2017

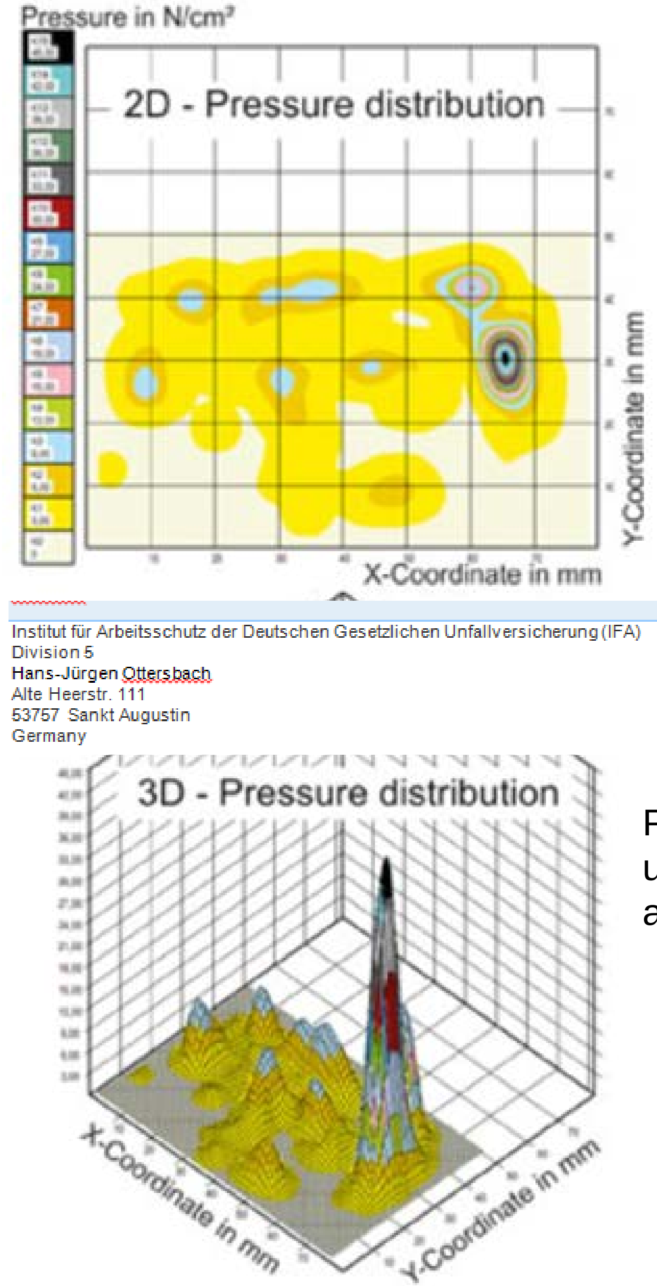
Test method attempts to replicate the performance of the target body part

Validation of power and force limited collaborative robot applications, requires real time testing based on the risk assessment, using specialized sensors and measurements, of any forces applied to exposed parts of the human body, to assure that they are below maximum levels to prevent pain or injury



Transient contact event recording here showing both initial transient contact and continued clamping forces

Adapted from ANSI/RIA TR R15.606

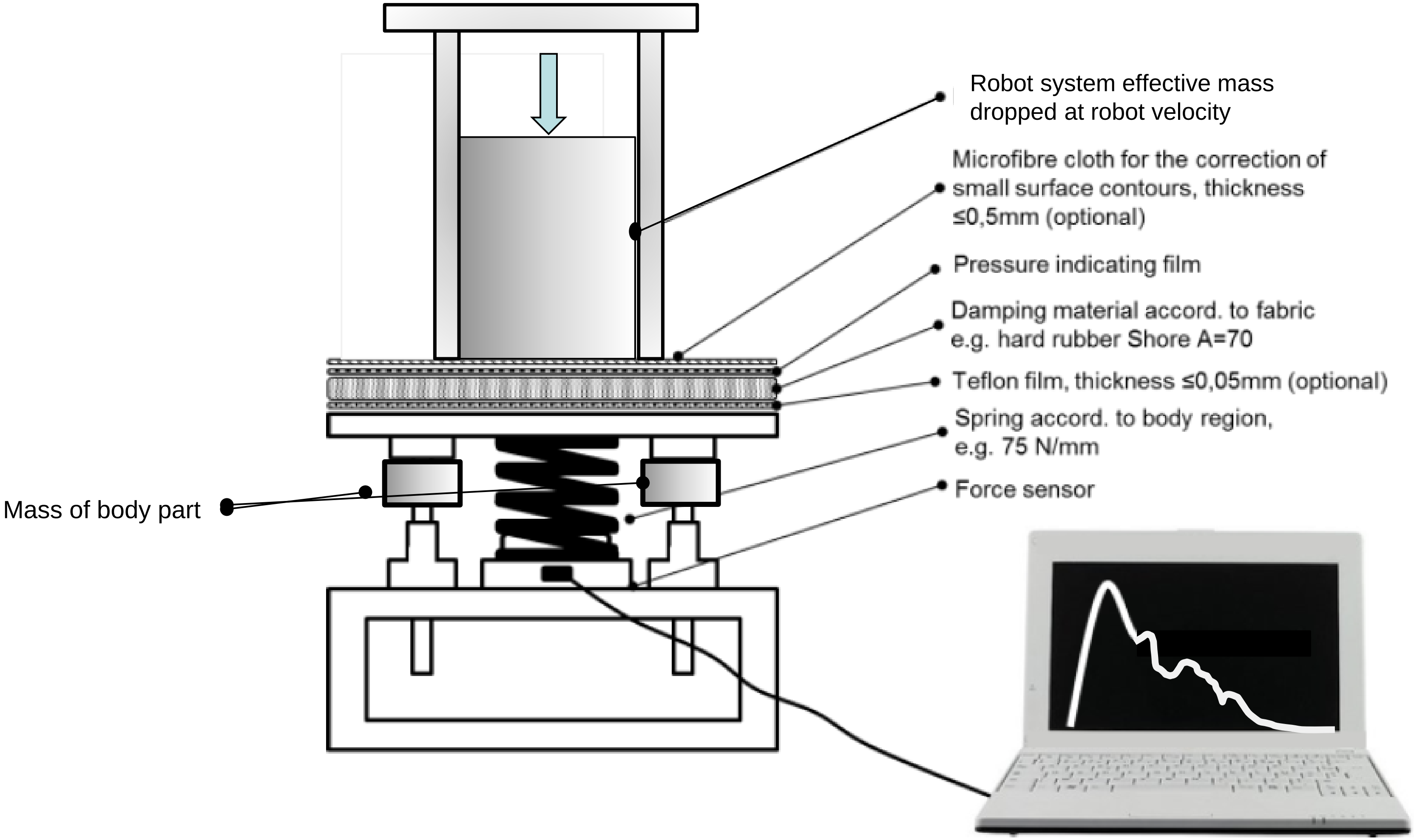


Pressure map for quasi-static test using body specific shore value pad and pressure mapping film

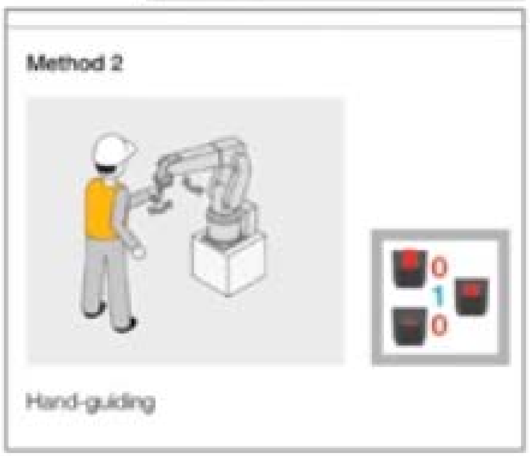
Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA)
Division 5
Hans-Jürgen Ottersbach
Alte Heerstr. 111
53757 Sankt Augustin
Apr 2013

Measuring transient impact

Concept being developed



Collaborative Robot Application Synopsis



Collaborative type	Benefit	High Risk Applications?	Low Risk Applications
Safety-rated monitored stop	Quicker resumption of operation (power retained)	**Yes** safeguarding required	**Yes**
Hand-guided	Personal control & responsibility by operator; high variability of programs & quick changes	**Yes**	**Yes**
Speed & Separation Monitoring	Reduced space for application; Immediate resumption of higher speeds	**Yes** safeguarding required for intrusion/ approach	**Yes** safeguarding required for intrusion/ approach
Power & Force Limiting *(without protective devices)*	Reduced space for application; if easy to program, then personal control by operator	**Yes, but LOW speed (might be <u>VERY</u> SLOW)**	**Yes**

Graphic Source: R. Nelson Shea, NRSC 2016 Presentation. Used with permission.
Information Source: ISO/TS 15066:2016.

References

- ANSI B11.0 Safety of Machinery General Requirements and Risk Assessment
- ANSI B11.19 *Performance Requirements for Risk Reduction Measures: Safeguarding and other Means of Reducing Risk*
- ANSI/RIA 15.06 Industrial Robot and Robot Systems- Safety Requirements
- ANSI/RIA TR R15.306 Risk Assessment
- ANSI/RIA TR R15.406 Safeguarding
- ANSI/RIA TR R15.606 Collaborative Robots
- ANSI/RIA TR R15.706 User Guide
- ANSI/RIA TR R15.806 Testing Methods for Power & Force Limited Collaborative Applications
- ISO 13849-1 Safety of machinery -- Safety-related parts of control systems -- Part 1: General principles for design
- ANSI/ASSP Z244-1 The Control of Hazardous Energy Lockout, Tagout and Alternative Methods

Contact Information

Questions?

Heinz Knackstedt
Safety Specialist
TÜV Functional Safety Engineer Machinery
C&E Advanced Technologies
677 Congress Park Drive
Dayton, Ohio USA 45459

Office: (937) 434-8830 x252
Cell: (937) 545-6494
hknackstedt@CEAdvancedTech.com