첨단제조로봇 국제 표준화 동향 및 이슈 제안

2021. 12. 16

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로봇 시장의 변화

Background

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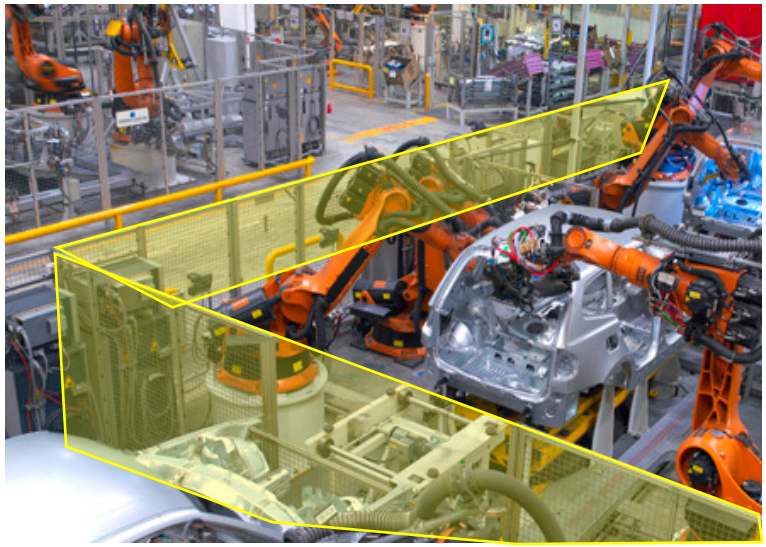
Robots inside of Safety Fence



Need space for safety fence

Intrinsic safety

Limited chance of collaboration

Intrinsic safety!

Robots without Safety Fence

Robots sharing workspace with human

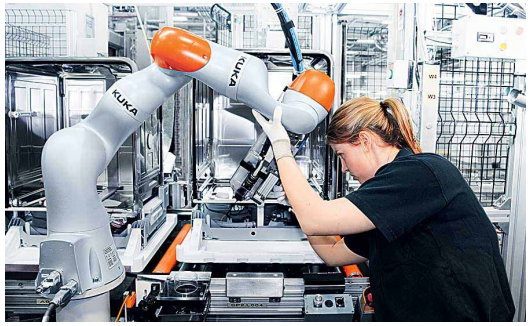
Robots collaborating with human

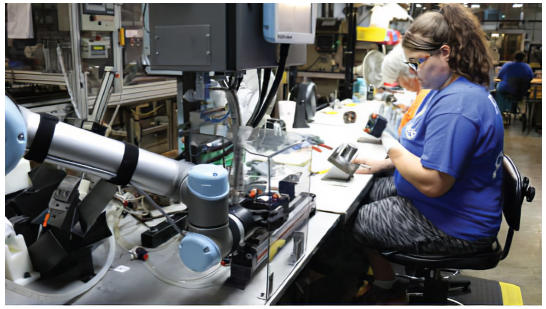
Collaborative Robot or Co-Bot!

More chance of contact (collision) and complicated safety measures!

Background

Wave of Collaborative Robots





2020

Mobile Manipulators

Background

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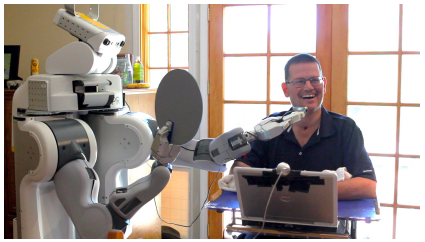
Not just in industrial environment but everywhere!



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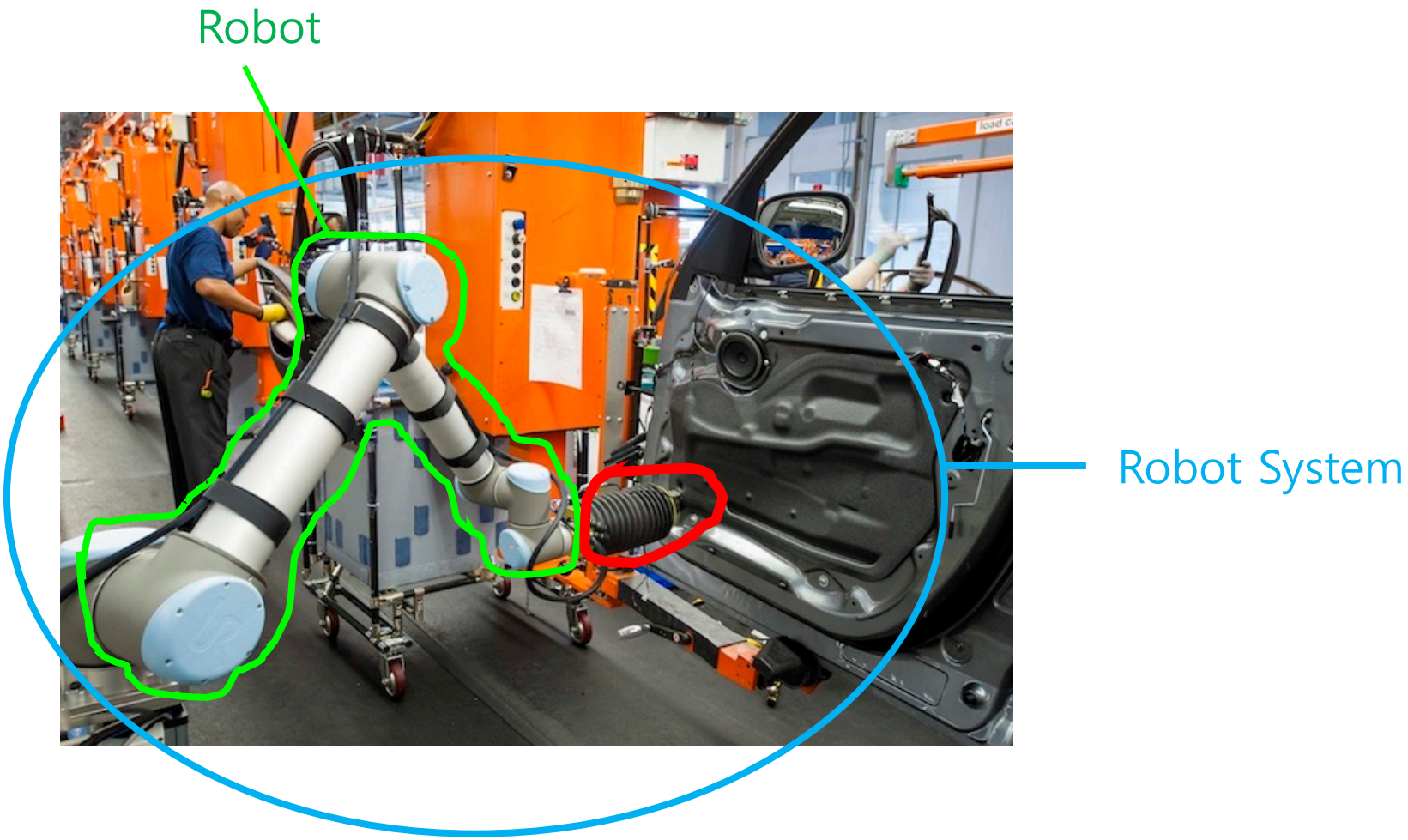
산업용로봇 관련 표준

산업용로봇 & 산업용로봇 시스템



산업용로봇 표준 Scope

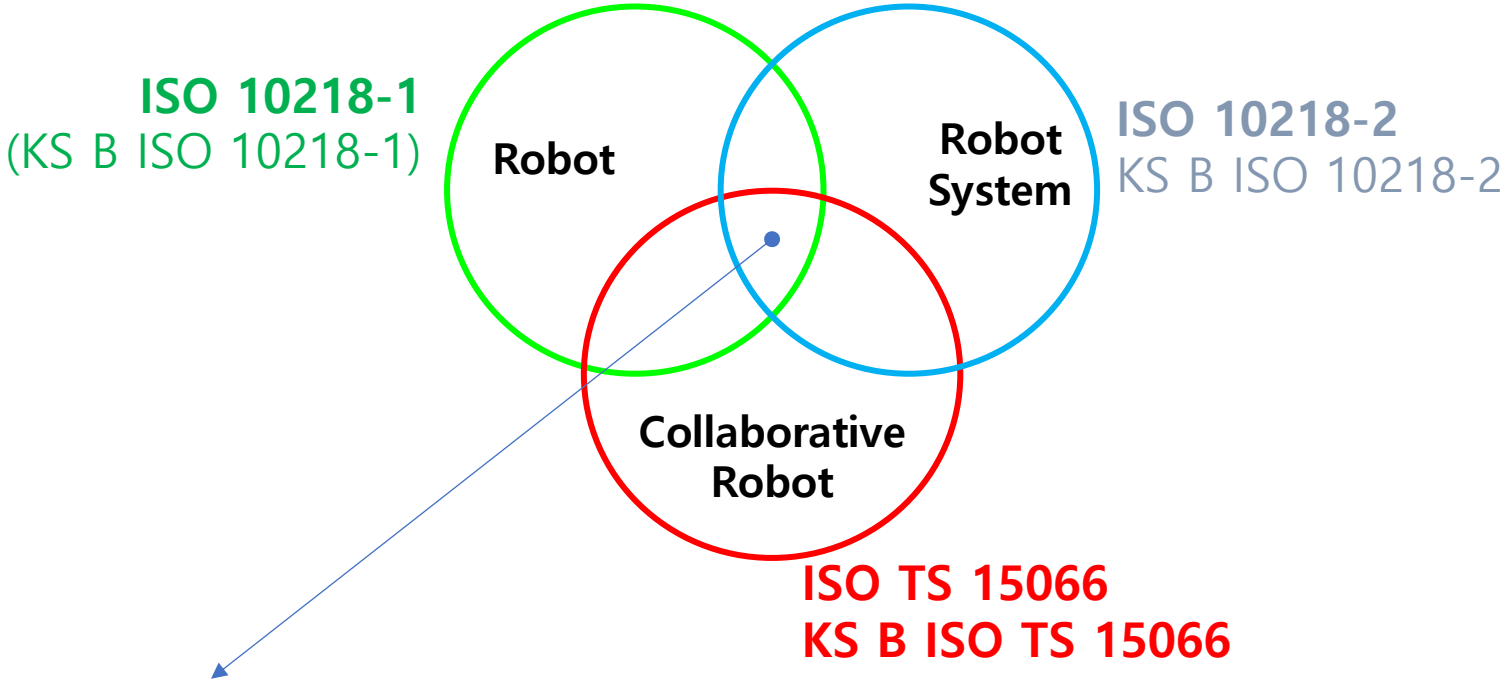
- **ISO 10218-1**:2011 Robots and robotic devices -- Safety requirements for industrial robots -- Part 1: Robot

- **ISO 10218-2**:2011 Robots and robotic devices -- Safety requirements for industrial robots -- Part 2: Robot systems and integration

- **ISO/TS 15066**:2016 Robots and robotic devices -- Collaborative robots

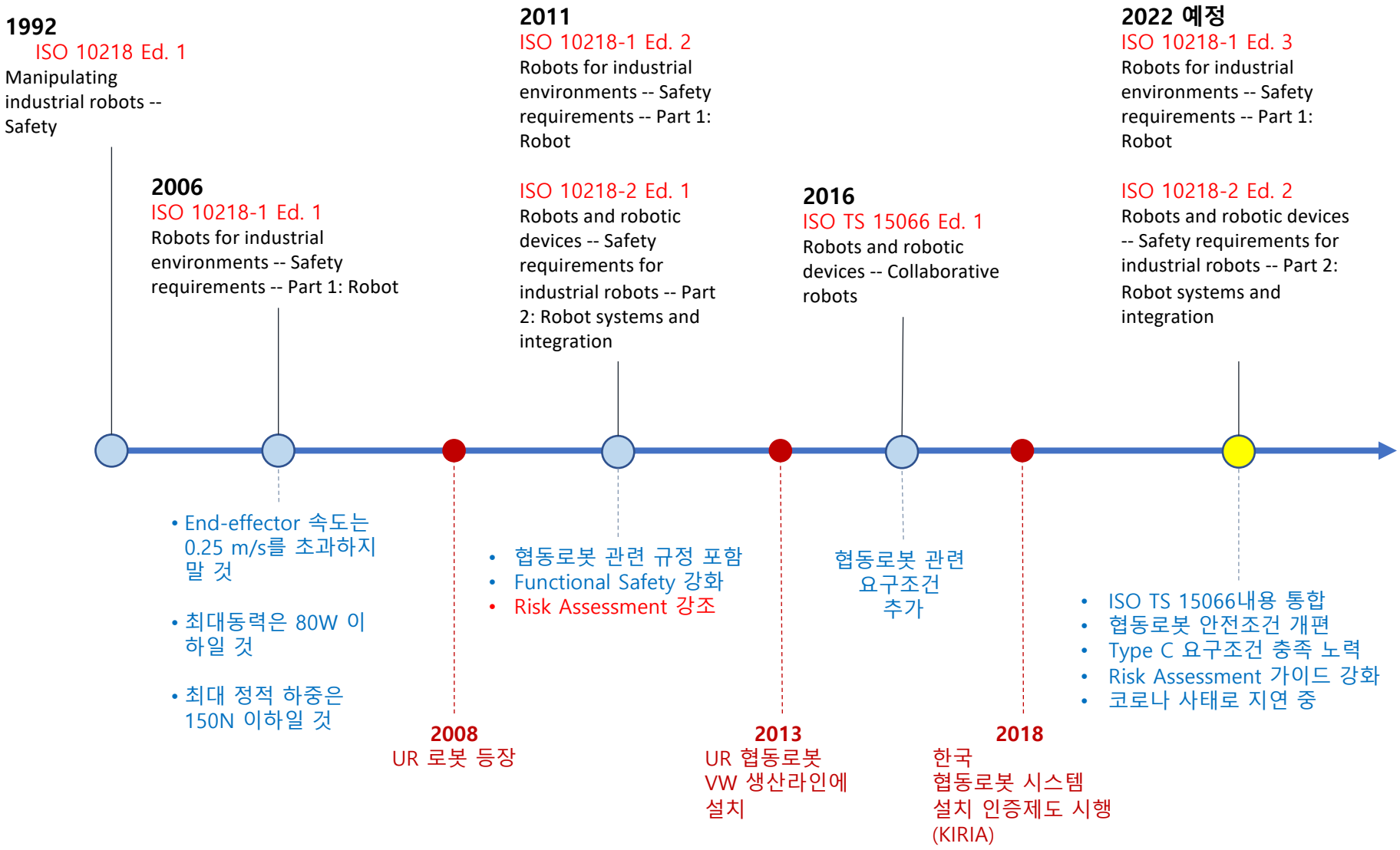
협동로봇 관련 국제표준 현황

- Industrial Robot에 적용되는 표준: ISO 10218-1,2 & ISO TS 15066
- ISO TS 15066은 "협동로봇+협동로봇 시스템"에 대한 표준



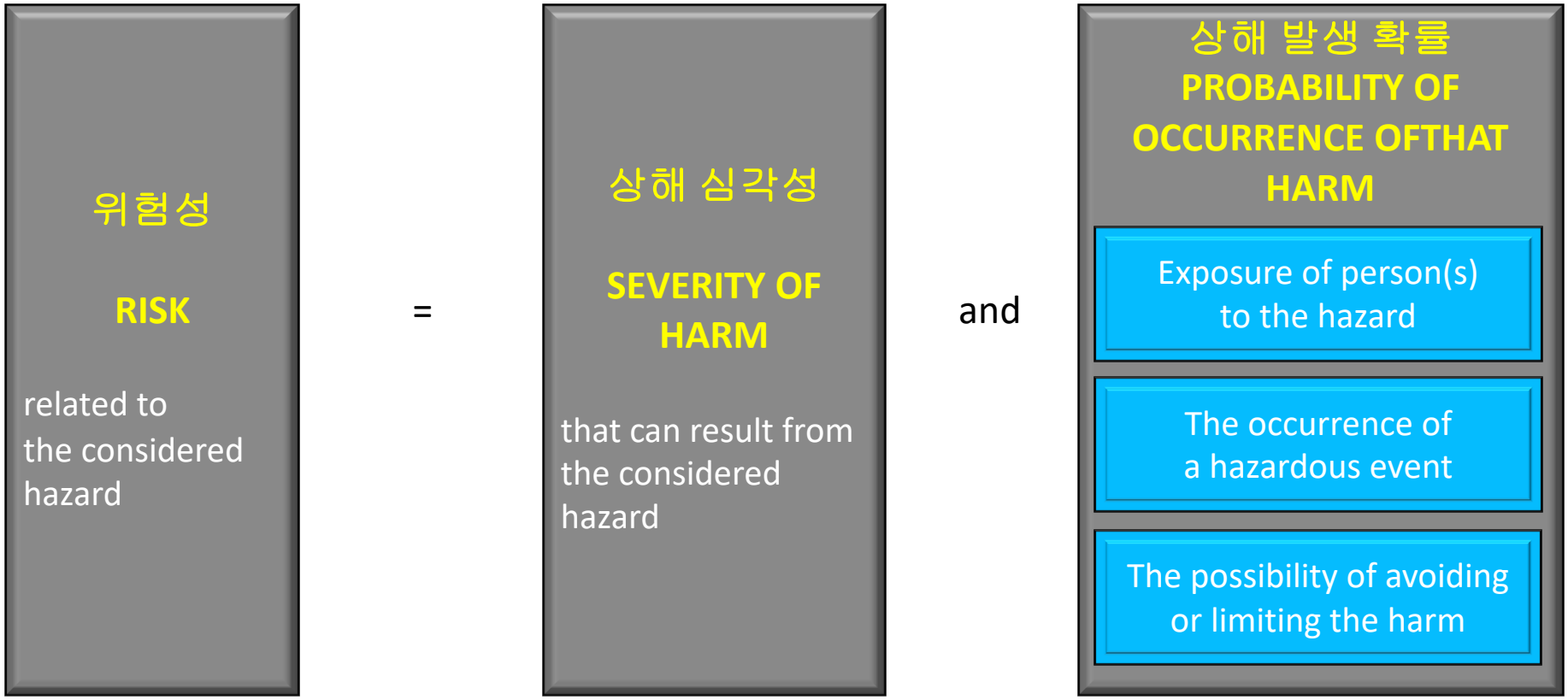
ISO 13849-1
- 기능안전성(Functional Safety) 요구조건 PL d

산업용로봇 관련 국제표준



용어 정의

- 위험성 (risk)
  - 상해 발생 확률과 상해 심각성의 정도
  - Combination of the **probability** of occurrence of **harm** and the **severity** of that harm



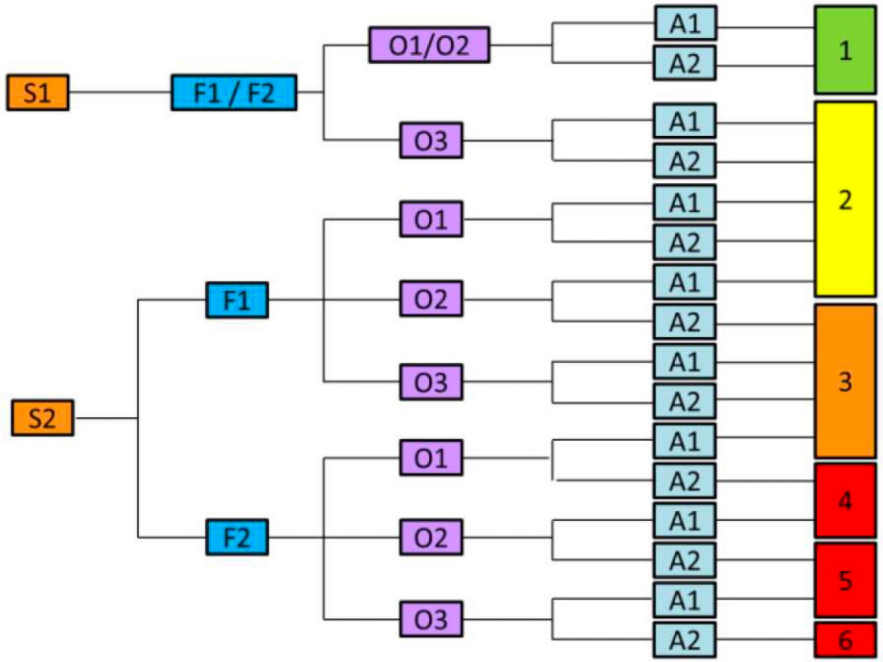
안전기능(Safety Function)

- **Functions whose failure can cause the change of the risk of the robot system.**

  - Safety related stop function initiated by safeguard
  - Local control function
  - Hold to run
  - Enabling device
  - Muting function
  - Prevention of unexpected start up
  - Control modes and mode selection
  - Emergency stop

위험성 추정/예측 (Risk Estimation) 예시 - Risk Graphs

- S, F, O, A 방법
  - **S**everity of Possible Harm
  - **F**requency and/or Duration of Exposure
  - Possibility of **O**ccurrence of Hazardous Event
  - Possibility of **A**voidance



Level	Risk	Comment
1	Negligible Risk	현재설비에 대한 무시할 수 있는 위험이 존재함. 추가적인 위험감소 조치가 요구되지 않음.
2	Very Low Risk	현재설비에 대한 매우 낮은 수준의 위험이 존재함. 위험감소를 위한 상당한 조치가 요구되지 않으나, 개인보호구 또는 교육을 통한 조치가 요구될 수 있음.
3	Low Risk	현재설비에 대한 낮은 위험이 존재함. 위험감소 조치 반드시 고려해야함.
4	Significant Risk	현재설비에 대한 위험원과 관련된 위험은 위험 감소 대책을 요구하기에 충분히 중요합니다. 이러한 조치는 다음 적절한 기회에 실행되어야 합니다.
5	High Risk	현재설비에 대해 위험 감소조치가 바로 적용되어야하는 잠재적 위험이 존재함.
6	Very high Risk	현재설비에 대해 위험 감소조치가 바로 적용되어야하는위험이 존재하고, 안전관련 부서에 즉각 연락함.

안전관련 제어시스템(Safety-related Parts of Control System)

위험성 감소 →

Risk without Protective Measures	Risk without Safety-related Control	Risk with Safety-related Control	Acceptable Risk

Safety-related Control System 사용

- **Safety-related Control** : A control system in a machine should be regarded as being safety-related if it contributes to reducing any risk to an acceptable level or if it is required to function correctly to maintain or achieve safety.

- SRP/CS (Safety-related Parts of Control System)

기능안전성 (Functional Safety)

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- Functional Safety: Requirement on reliability of safety related functions necessary to sustain or fulfill the required safety.

- Hardware requirement

- Software requirement

SRP/CS의 PL 계산 관련 기본 개념

- MTTFd (Mean time to dangerous failure) : The MTTF assumes the fact that every system will fail if you just wait long enough.

- DC (Diagnostic Coverage) : Fractional decrease in the probability of dangerous hardware failures, resulting from the use of automatic diagnostic tests.

- PFHd (Average Probability of Dangerous Failure per Hour)

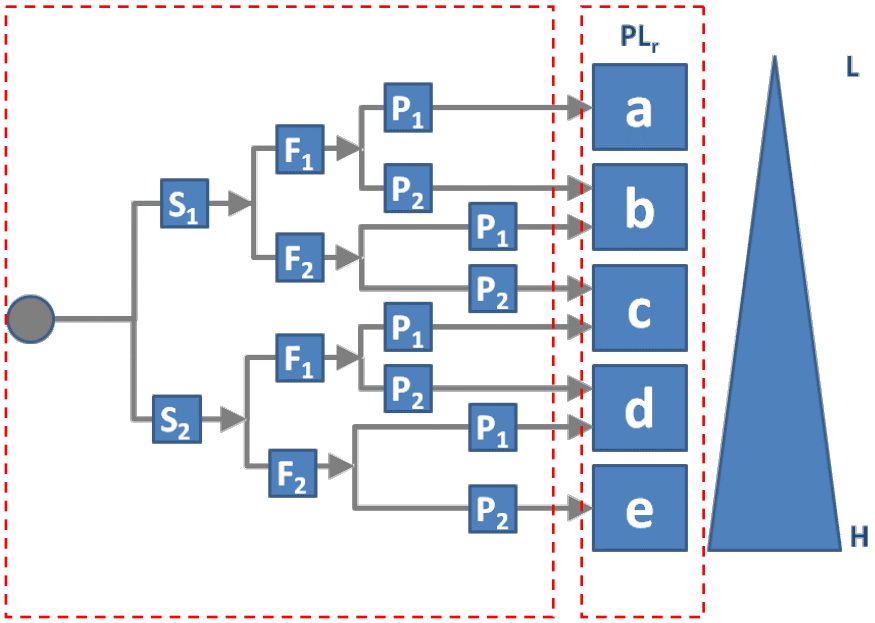
ISO 13849-1 및 IEC 61496-1에서 규정하는 PL(Performance Level) 조건 표

Performance Level (PL)	시간당 위험한 오류 발생 확률 (PFHd) 1/h	
a	$\geq 10^{-5}$ and $< 10^{-4}$	〈0.001% to 0.01%〉
b	$\geq 3 \times 10^{-6}$ and $< 10^{-5}$	〈0.0003% to 0.001%〉
c	$\geq 10^{-6}$ and $< 3 \times 10^{-6}$	〈0.0001% to 0.0003%〉
d	$\geq 10^{-7}$ and $< 10^{-6}$	〈0.00001% to 0.0001%〉
e	$\geq 10^{-8}$ and $< 10^{-7}$	〈0.000001% to 0.00001%〉

PLr (Required Performance Level) 결정 방법

- **Severity of Injury.**
  - S1 Slight injury, (bruise).
  - S2 Severe injury, (Amputation or death).
- **Frequency of exposure to injury.**
  - F1 Seldom.
  - F2 Frequent to continuous (Frequent to continuous are not defined in the standard).
- **Possibility of avoiding the hazard.**
  - P1 Possible.
  - P2 Less possible.

ISO 13849



Risk Analysis

Required Performance Level

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10218-1,2 개정 내용

ISO 10218 – 1, 2 **개정 방향 및 내용 – 주요 사항** (1)

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➢ Type C Standard

- 안전요구조건의 모호성에 대한 CEN의 문제 제기
- 위험성 평가 방법/결과의 재현성, 표준화 필요성 (S, F, O, A)
- Safety Function과 그에 대한 요구조건 구체적 명시

➢ Risk Assessment 관련 파라메터 기준값 제시

- 일관성 있는 Risk Assessment 결과값 도출을 위한 가이드라인 제시

➢ Robot Classification

- Class 1 and 2
- Class에 따른 위험성 평가 및 안전 요구조건

Risk Assessment 관련 파라메터 기준값 제시

- ISO 10218-2 개정판

Table C. 2 – Examples for determining severity parameters

Injury severity parameters and ranges					
Hazard Type	**Injury Type**	**Minor (S1)**	**Moderate (S2)**	**Serious (S3)**	**Catastrophic (S4)**
Mechanical	**Lacerations or Amputations**** [40], [34] Amputation force is derived from literature search that identified, when using an 80 mm diameter load cell, pain and fracture thresholds at — 150 N; — 400 N; — 2000 N	Minor/superficial cuts requiring bandaging treatment; typically caused by: — stationary blunt surfaces; — blunt edges with loads less than 28 kPa.	Lacerations not requiring sutures or other closure in lieu of sutures, typically caused by the following: — stationary sharp edges; — blunt, sharp edges.	Lacerations requiring sutures or other closure in lieu of sutures or partial blindness typically caused by: — flying projectiles; — stationary sharp edges; — blunt, sharp edges. Amputation of finger(s) or toe(s) not leading to impaired hand use or impaired walking abilities (disabling injury), typically caused by: — sharp edges mechanically in motion (e.g. rotating, reciprocating, shearing); — offset, blunt edges with loads exceeding 28 kPa.	Lacerations or amputation that could result in death or permanently disabling injury such as blindness. e.g. amputation of hands, feet, arms, legs, or loss of eyes

Risk Assessment 관련 파라메터 기준값 제시

- ISO 10218-2 개정판

Table C. 3 – Examples for determining exposure parameters

Element of risk according to ISO 12100	Parameter	Application Group A: seldom interaction	Application Group B: cyclic interaction	Application Group C: constant interaction	Range
Exposure	Frequency			Not applicable	Low
		Refer to Group B →		Not applicable	Medium
		Refer to Group B →			High
	Duration[1]	Maximum 1h total per week	*in*	Not applicable	Short
		Refer to Group B →		Not applicable	Medium
		Refer to Group B →			Long
	Number of persons exposed	Certain persons are exposed but are not related to any specific task			Some
		One person exposed			One
		More than one person exposed			More than 1

Robot Class

- ISO 10218-1 개정판

Robot Class	Total mass per manipulator (M) [kg]	Maximum force* per manipulator (F_{MPM}) [N]	Maximum speed [mm/s]
I	10 kg and under	50 and under	250 mm/s and under
II	Over 10 kg	Over 50	Over 250 mm/s

ISO 10218 – 1, 2 개정 방향 및 내용 – 주요 사항 (2)

- PL d → PL r
  - 모든 Safety Function에 대해 PL d를 요구 → Safety Function별, 로봇 Class별 required PL (PL r) 조건 다양화

- ISO/TS 15066 내용 포함

- Test methodology to determine the maximum force per manipulator for Class I robots.
  - 충돌 힘, 충돌 압력 측정 방법 제시

- ISO/TR 20218-1 (end-effectors), ISO/TR 20218-2 (manual load/unload) 내용 포함

- Communication Safety
  - Cybersecurity

Functional Safety Requirements & PL d → PL r

Clause	Mandatory, Conditional or Optional[a]	Safety Function Name	Possible Triggering Event	Intended Result *unless "OR" is stated within a given group, ALL are required*	default functional safety PL_r or SIL
5.7.9	Conditional	**simultaneous motion – restriction of robot selection**	Selection of robots to be under simultaneous control	— Only robots in the same mode can be selected for simultaneous motion	**PLd or SIL 2**
5.7.9	Conditional Mandatory for simultaneous control	**restriction of non-selected robot(s) motion**	Selection of robots to be under simultaneous control	— Any robot not selected shall be in a monitored-standstill	**PLd or SIL 2**
5.9.1 d)	Conditional	**end-effector position** [c]	Robot pose/ end-effector position is not in correct position for the intended operation of the end-effector (e.g. open, close, on, off)	— Prevent the intended operation of the end-effector (e.g. open, close, on, off)	**PLc or SIL 1**
5.9.1d) 5.9.4c)	Optional	**end-effector gripping force**[c]	Gripping force is outside of set parameter(s)	— Protective stop (e.g. low gripping force could result in loss of workpiece); and/or — Reverse of the closing movement (e.g. when high gripping force could result in injury)	**PLc or SIL 1**
5.9.1j) 5.9.6	Optional	**release of detachable tool monitoring**[c]	Detachable tool not in designated location/ condition	— Prevent release of detachable tool	**PLc or SIL1**
5.9.4a)	Optional	**end-effector force** [b, c]	Applied force is outside of set parameters for the end-effector	— Protective stop requiring a reset (5.5.7.3) or Stop category 0 or 1 initiated (5.4.5)	**PLc or SIL 1**
5.9.4b)	Optional	**end-effector orientation monitoring** [b, c]	End-effector pose/ position is not in intended orientation	— Prevent the intended operation of the end-effector	**PLc or SIL 1**
5.9.4 b)	Optional	**orientation limiting** [b, c]	activate (by inputs or internally triggered) orientation limiting safety function	— Restrict orientation of the end-effector or wrist	**PLd or SIL 2**
5.9.4 e)	Optional	**end-effector presence sensing** [b, c]	Person is contacted or within a detection zone around the end-effector	— Protective stop	**PLc or SIL 1**

Functional Safety Requirements & PL d → PL r

E.2 Examples

E.2.1 Example 1 – based on ISO 12100:2010

PL_r is estimated from a results of risk estimation described in Annex C, C.2, as shown in Table E. 2 below.

Table E. 2 – PL_r assignment matrix[1]

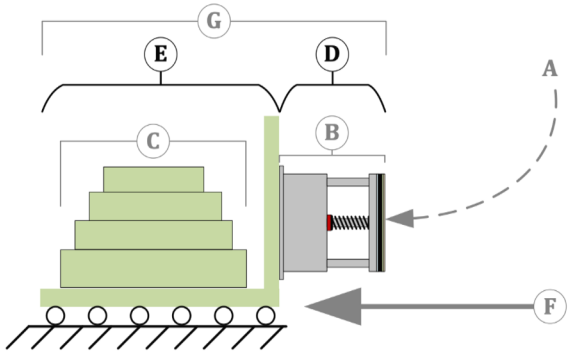
Severity	Exposure	Avoidance	Occurrence		
			O1	O2	O3
S1	E1	A1	a	a	a
		A2	a	a	a
		A3	a	a	a
	E2	A1	a	a	a
		A2	a	a	b
		A3	a	b	c
S2	E1	A1	a	a	a
		A2	a	a	b
		A3	a	b	c
	E2	A1	a	a	b
		A2	a	b	b
		A3	b	b	c
S3	E1	A1	b	c	c
		A2	c	c	c
		A3	c	c	d
	E2	A1	c	d	d
		A2	d	d	d
		A3	d	d	e
S4	E1	A1	d	d	d
		A2	d	d	d
		A3	d	d	e
	E2	A1	d	e	e
		A2	e	e	e
		A3	e	e	e
PLd and PLe: the architecture is according to 5.5.3					

Methodology for Collision Force and Pressure Evaluation

- ISO 10218-2에 포함

Test and/or Simulation

device with effective mass method. This method requires that the PFMD be allowed to move freely along the direction of contact as well as replicate the human body region effective mass m_H to directly measure pressure and force. The values for m_H per body region are shown in Table N.1. This method is shown in Figure N.3.Table



Key

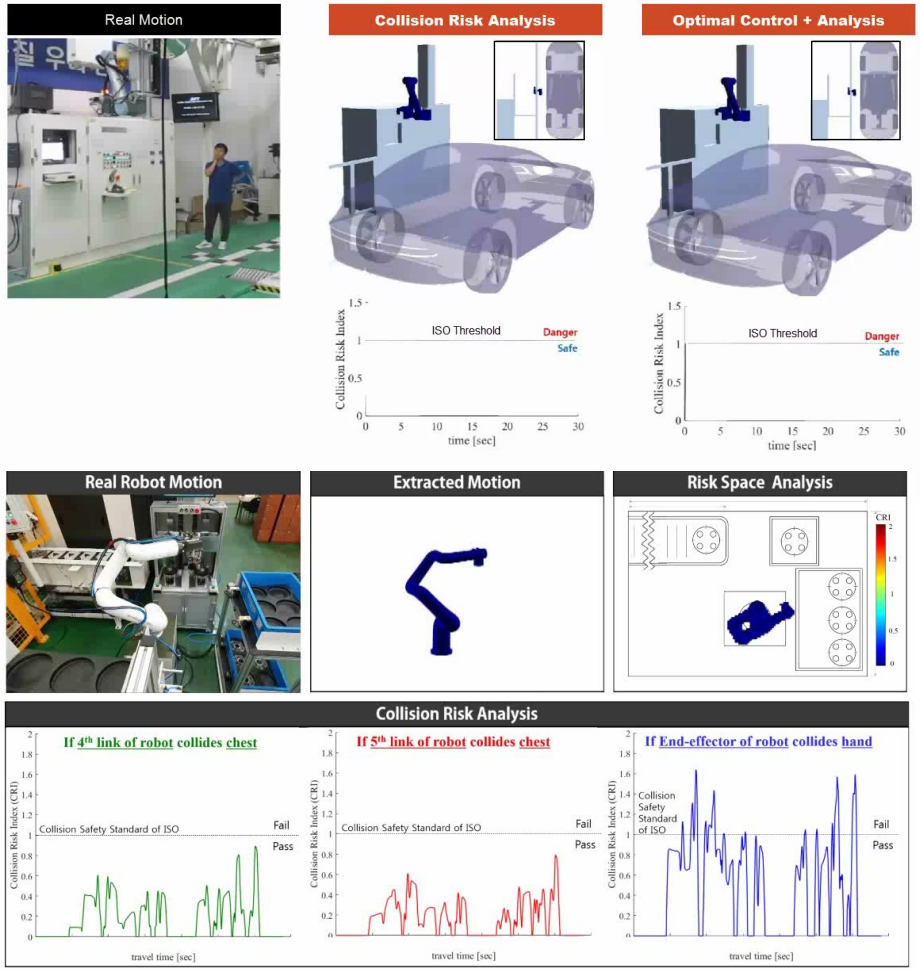
A	path of robot or end-effector or workpiece *(the object whose impact is being measured)*	**D**	additional mass
B	typical PFMD	**F**	direction of low friction movement
C	weights		
D	mass of PFMD		

NOTE: Additional wmass is added to achieve an effective body region mass as stated in Table N.1.

Figure N. 3 — Unconstrained PFMD mounted to a single axis low friction slide

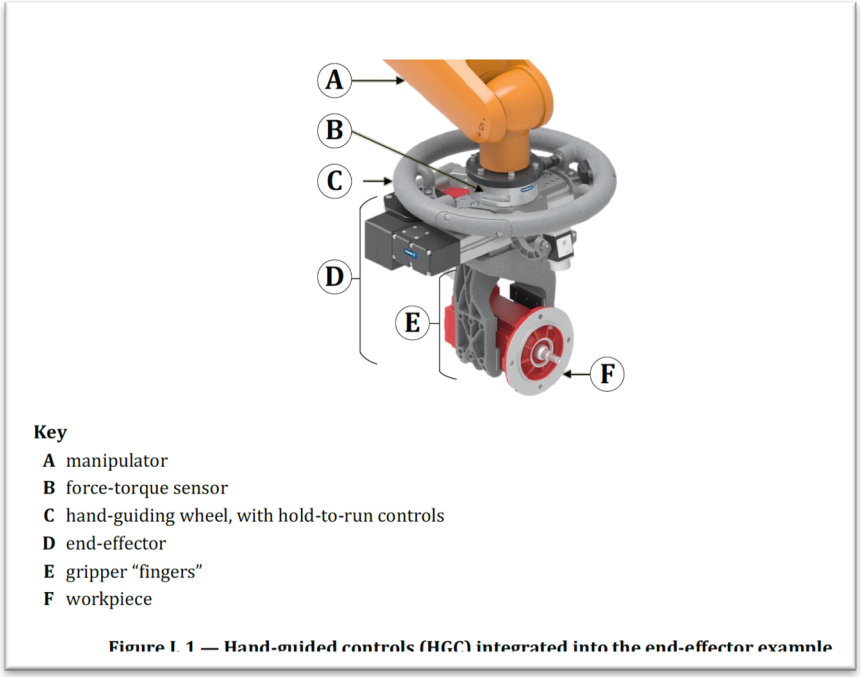
There is another measurement method under development: the quasi-static measurement with transient contact pressure and force conversion method. This method is conducted using a quasi-static contact Where the measured pressure and force are converted per body region. A pressure and force calculation method is

HYUNDAI



ISO/TR 20218-1, ISO/TR 20218-2 내용 포함

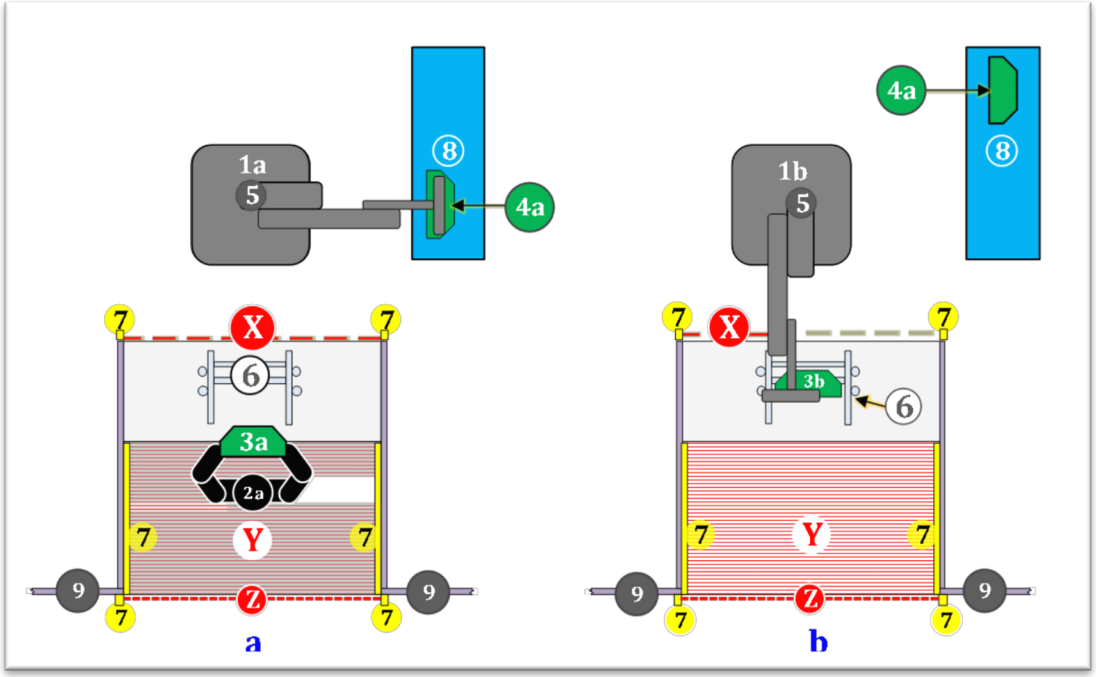
- ISO 10218-2에 포함



Key

A manipulator
B force-torque sensor
C hand-guiding wheel, with hold-to-run controls
D end-effector
E gripper "fingers"
F workpiece

Figure I.1 — Hand-guided controls (HGC) integrated into the end-effector example



ISO 10218 – 1, 2 개정 방향 및 내용 – 기타 사항

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- category 2 stopping functions;
- definitions and abbreviations;
- details within the information for use clause;
- functional safety requirements;
- hand-guided control (HGC) requirements;
- markings;
- mechanical strength and stability requirements;
- mode selection;
- power loss requirements;
- hand-guided controls (HGC) requirements;
- spaces (maximum, restricted) figures shown in Annex B;
- speed and separation monitoring (SSM) requirements to enable collaborative applications;
- the term “collaborative robot” is not used

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모바일 매니퓰레이터 관련 표준

Mobile Manipulator 표준 Gap

Mobile manipulation
(moving mobile platform + moving manipulator)

Manipulator가 부착된 상황에서 Mobile platform의 설계 및 안전 요구조건에 대한 표준 항목 없음

Mobile platform에 부착된 상황에서 manipulator의 설계 및 안전 요구조건에 대한 표준 항목 없음.

Mobility

ISO 3691-4

ANSI/
ITSDF
B56.5

ISO
13482

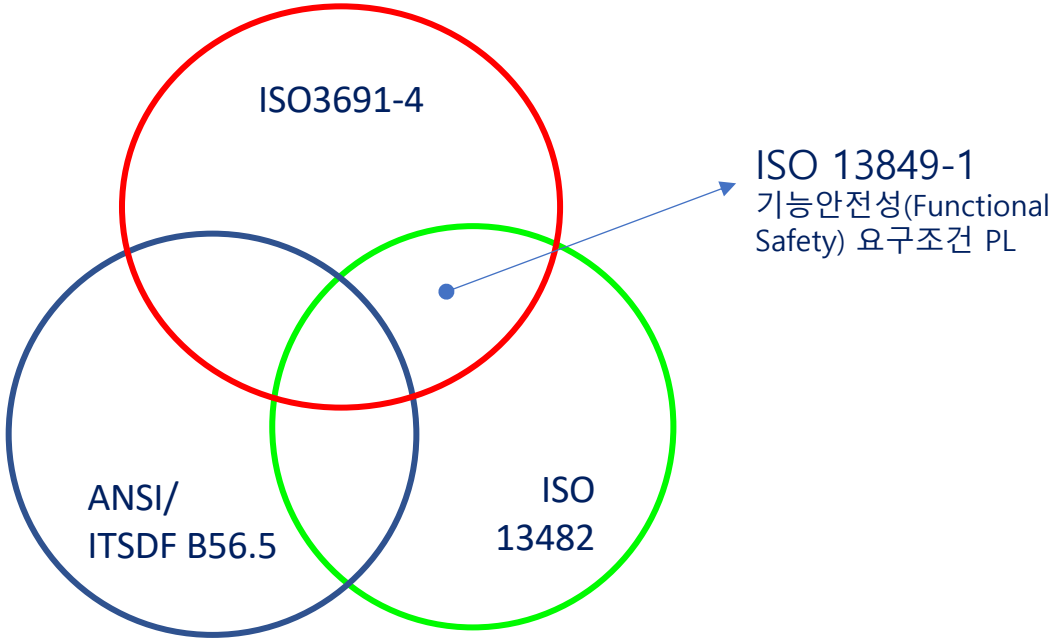
Manipulation

ISO
10218-1

ISO
10218-2

ISO
15066

Mobility 관련 국제표준 현황



- ISO 3691-4 Industrial trucks – Safety requirements and verification – Part 4: Driverless industrial trucks and their systems
- ISO 13482:2014 Robots and robotic devices -- Safety requirements for personal care robots
- ANSI/ITSDF B56.5:2012 Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles

Safety Requirements for Mobile Manipulator

- Performance (또는 수행가능 task 종류)와 요구되는 Safe Function사이에 상관성이 있음.
  - 예) 충돌감지 기능의 향상 → 고속 운전 가능

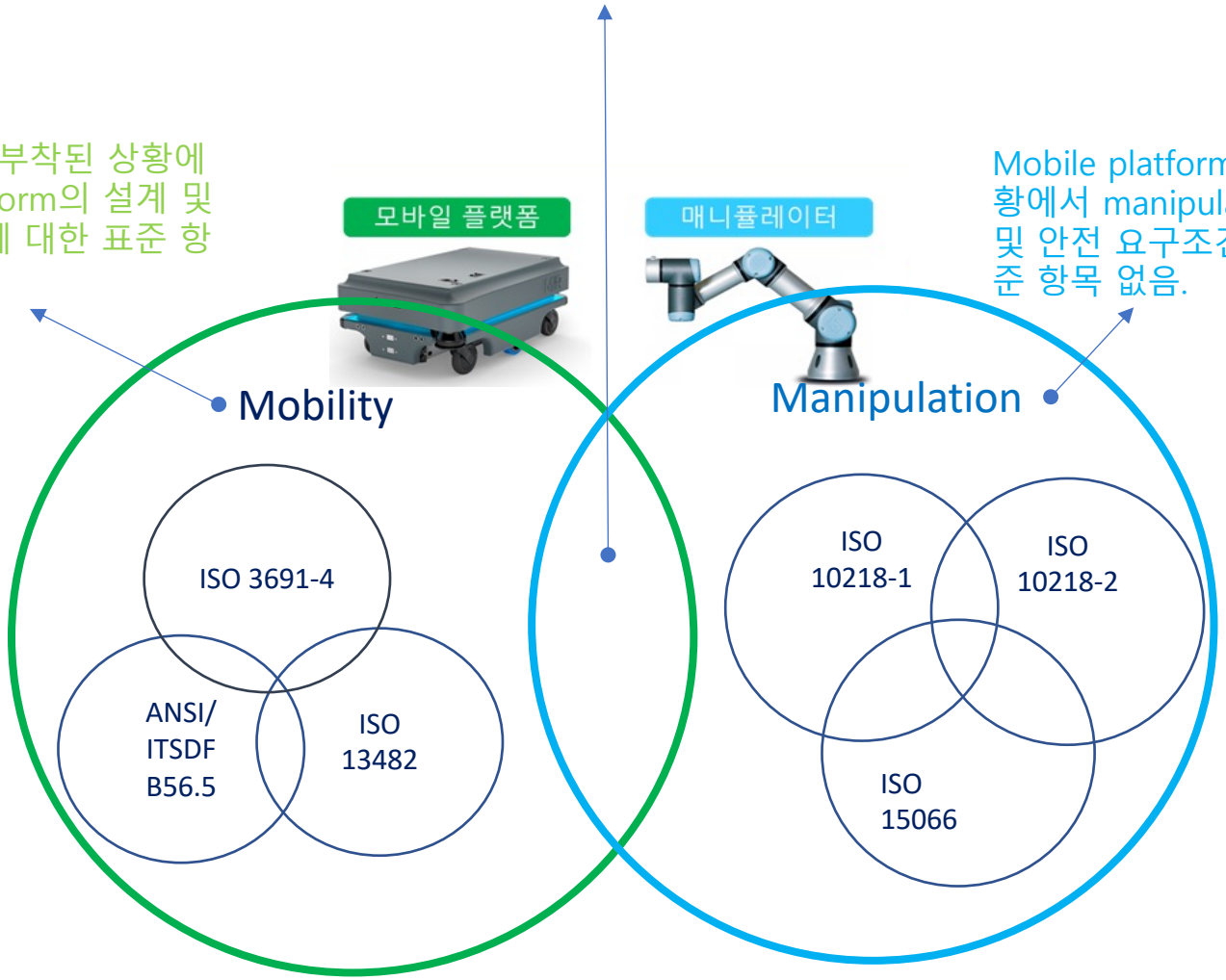
OPERATIONAL CONDITIONS	Moving AGV + Stationary Robot		Stationary AGV + Moving Robot		Moving AGV + Moving Robot	
	Single	Dual	Single	Dual	Single	Dual
Unexpected startup of robot or AGV	A/R	A/R	A/R	A/R	A/R	A/R
Robot/AGV hardware safety interlock	A/R	A/R	A/R	A/R	A/R	A/R
Human approach angle other than current direction of AGV travel, human is… …in robot work volume, in AGV path …out of robot work volume, in AGV path …in robot work volume, out of AGV path	A/R A R	A/R A R	A/R A R	A/R A R	A/R A R	A/R A R
AGV position uncertainty	A	A	A	A	A	A
Robot position uncertainty	R	R	R	R	R	R
Conflicting emergency stop situations	A	A	A	A	A	A
Robot sensing within the restricted space	A	A	A/R	A/R	A	A
Mobile manipulator stability	A	A	A	A	A	A
Overhanging obstacle extends into robot or AGV path	A	A	A	A	A	A
Reporting joint configuration of robot	A/R	A	A/R	A	A/R	A
Robot/AGV inhibiting motion of the other	A/R	A	A/R	A	A/R	A
Planned/automatic restart from pause/stop	A/R	A	A/R	A	A/R	A
Sensing beyond vehicle path	A/R	R	A/R	R	A/R	R
Competing/incompatible safety protocols	A/R	--	A/R	--	A/R	--
Human carrying large load into AGV/robot path and vice versa	--	--	A/R	--	--	--
Velocity of any point greater than that of AGV/robot	NOT APPLICABLE				R	--
Unplanned restart from pause/stop	A/R	--	A/R	--	A/R	--
Error recovery startup	R	--	R	--	R	--
AGV/robot software safety interlock	R	--	R	--	R	--
AGV/robot position/configuration update and verification	A/R	--	A/R	--	A/R	--
AGV/robot assumes master control during a pause event	A	--	A	--	A	--

Mobile Manipulator 표준 Gap

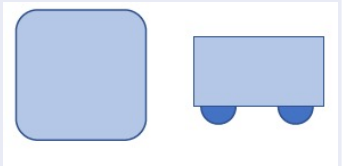
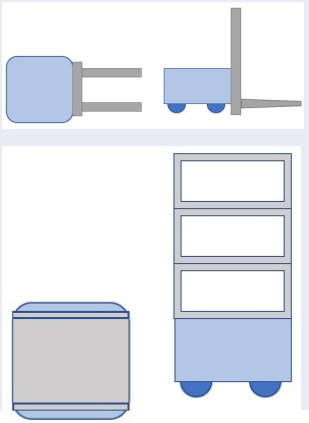
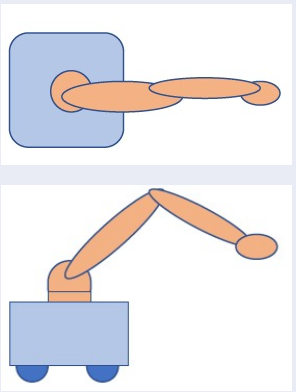
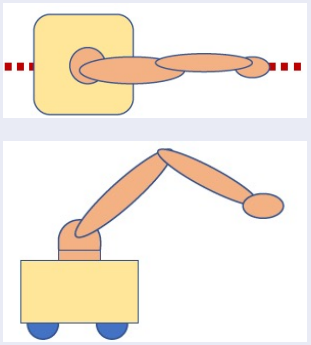
ANSI/RIA R15.08-1-2020 Industrial Mobile Robots - Safety Requirements - Part 1: Requirements For The Industrial Mobile Robot

Manipulator가 부착된 상황에서 Mobile platform의 설계 및 안전 요구조건에 대한 표준 항목 없음

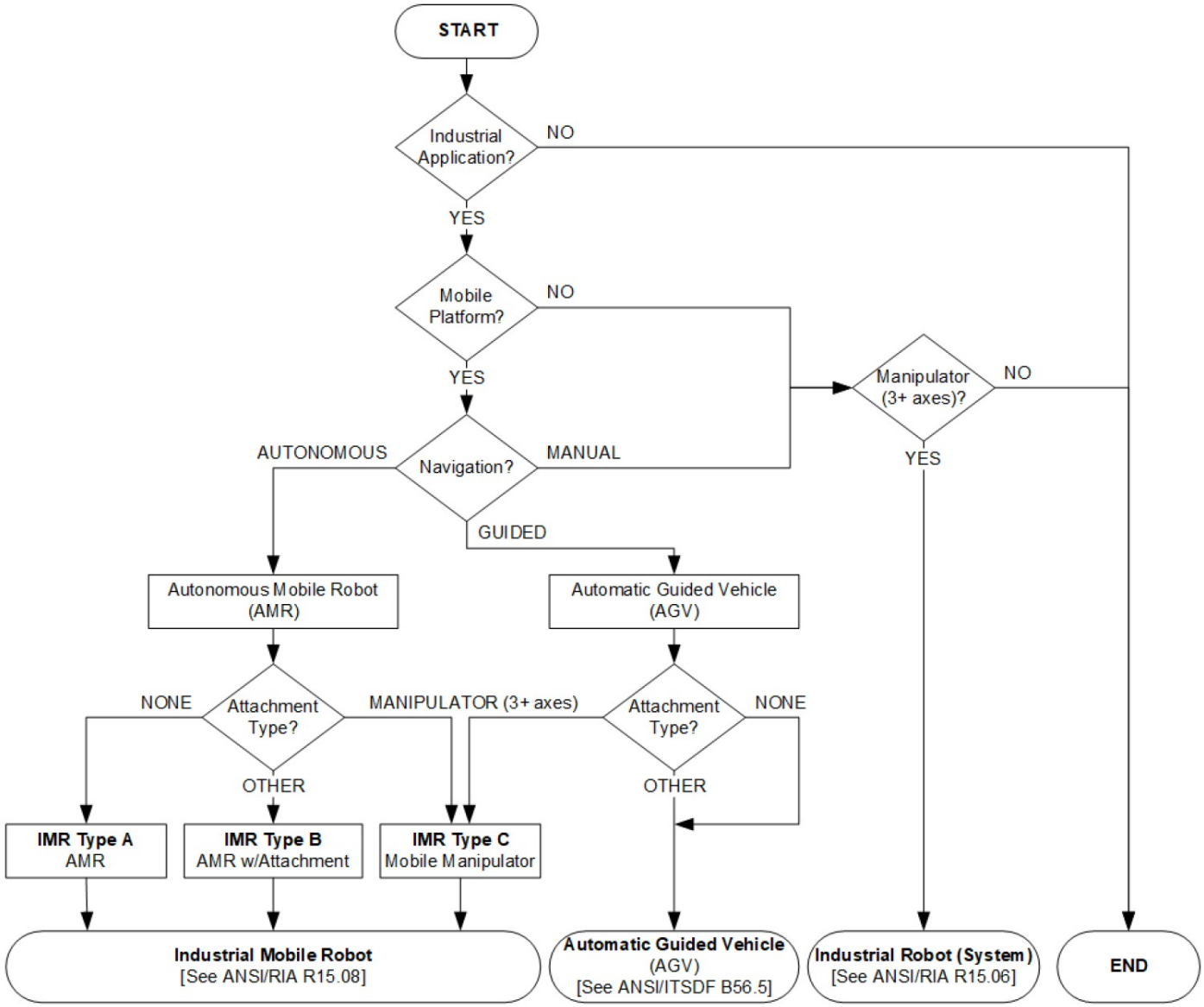
Mobile platform에 부착된 상황에서 manipulator의 설계 및 안전 요구조건에 대한 표준 항목 없음.



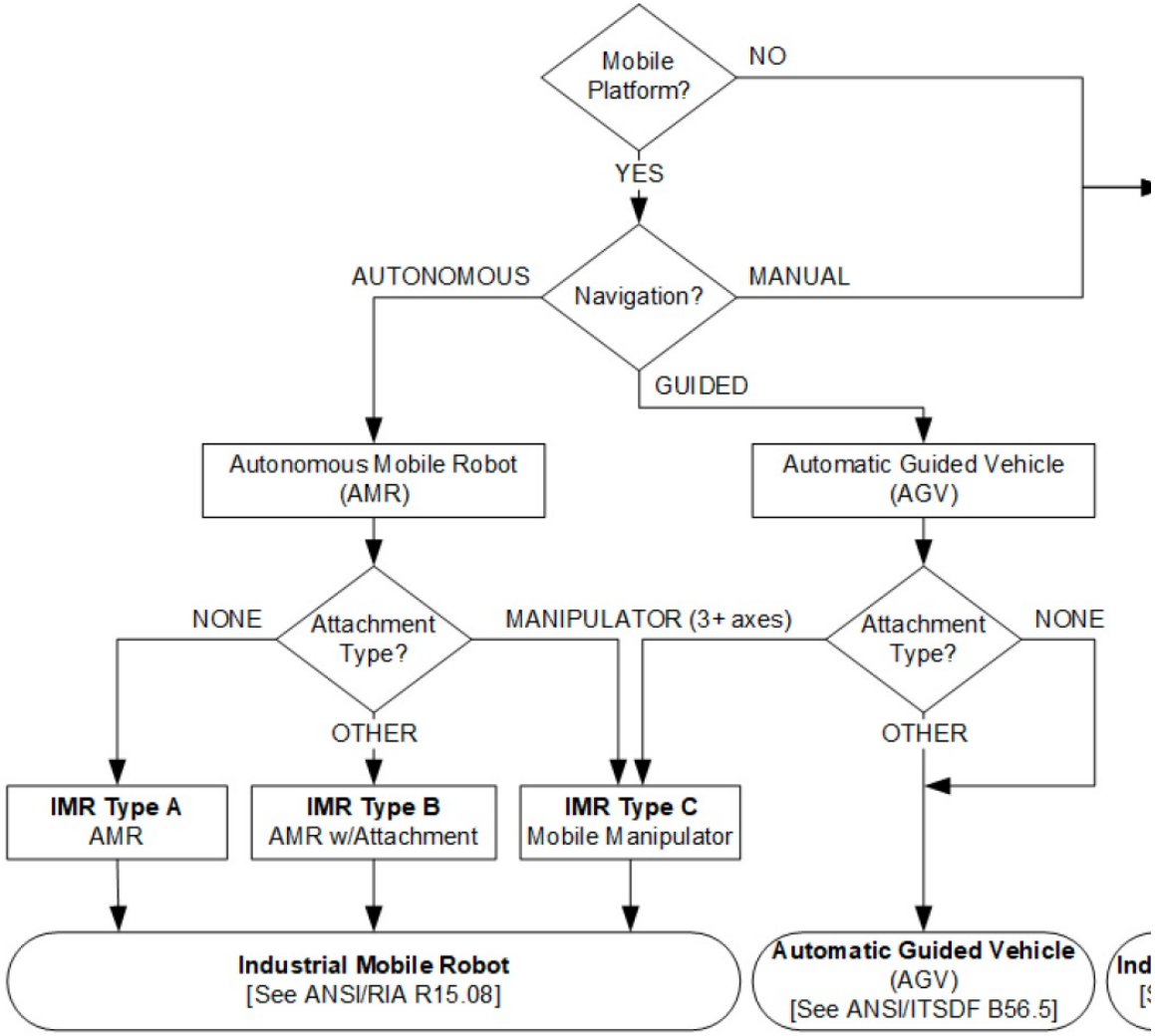
Proposed types of IMR by RIA 15.08 Group

Mobile Platform	AMR	AMR	AMR	AGV
Attachment	None	• After-market, non-robotic attachment (passive or articulated) • Stock articulated attachments	Robotic attachment (manipulator, arm, industrial robot per ISO 10218)	Robotic attachment (manipulator, arm, industrial robot per ISO 10218)
Examples				 (Dashed line: Guide Path)

Proposed types of IMR by RIA 15.08 Group



Proposed types of IMR by RIA 15.08 Group



Proposed types of IMR by RIA 15.08 Group

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B.1 IMR Type A: Autonomous mobile robot (AMR); no attachment(s)

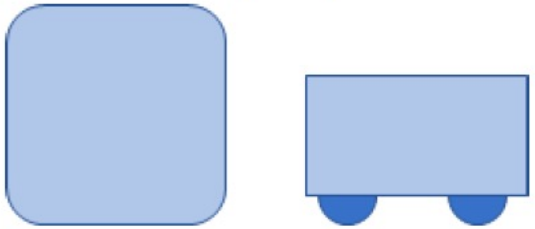

Figure B.1: Example of an IMR Type A, an AMR with no attachments.

(L: Plan View; R: Elevation View.)

Proposed types of IMR by RIA 15.08 Group

B.2 IMR Type B: AMR with attachment(s); attachments do not include a powered manipulator

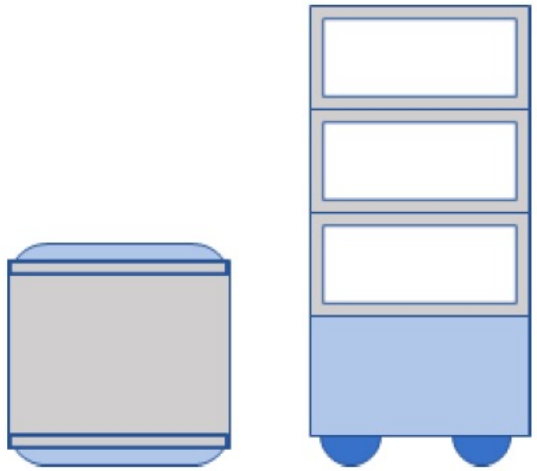

Figure B.2.i.: Example of an IMR Type B, an AMR with attachment(s) that do not include powered manipulator(s); in this case, a passive attachment (shelf unit).

(L: Plan View; R: Elevation View.)

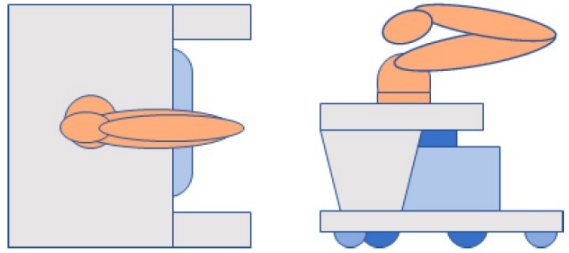

Figure B.2.iii.: Example of an IMR Type B, an AMR with attachment(s) that do not include powered manipulator(s); in this case, a manipulator that is being transported in a stowed and unpowered state (e.g., as payload).

(L: Plan View; R: Elevation View.)

Proposed types of IMR by RIA 15.08 Group

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B.3 IMR Type C: Mobile platform with manipulator attachment

NOTE: The mobile platform could be either an automatic guided vehicle (AGV) or an autonomous mobile robot (AMR). The manipulator is intended to be powered, and at least potentially operational in automatic mode, during mobile platform operation.

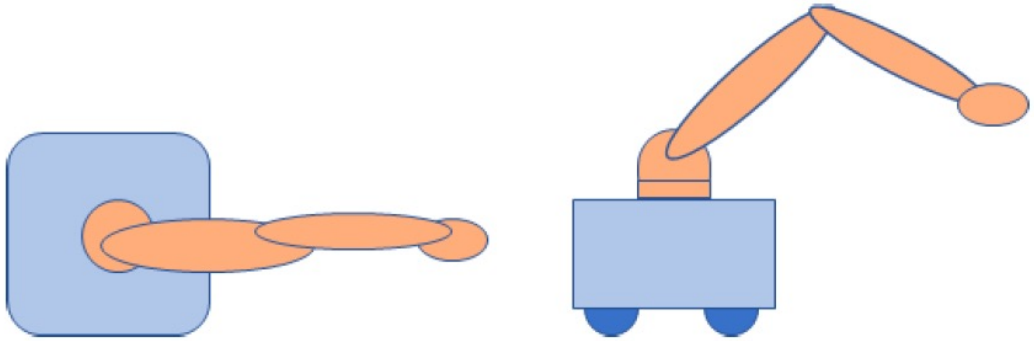

Figure B.3.i.: Example of an IMR Type C, a mobile platform (in this case, an AMR), with a manipulator attachment.

(L: Plan View; R: Elevation View.)

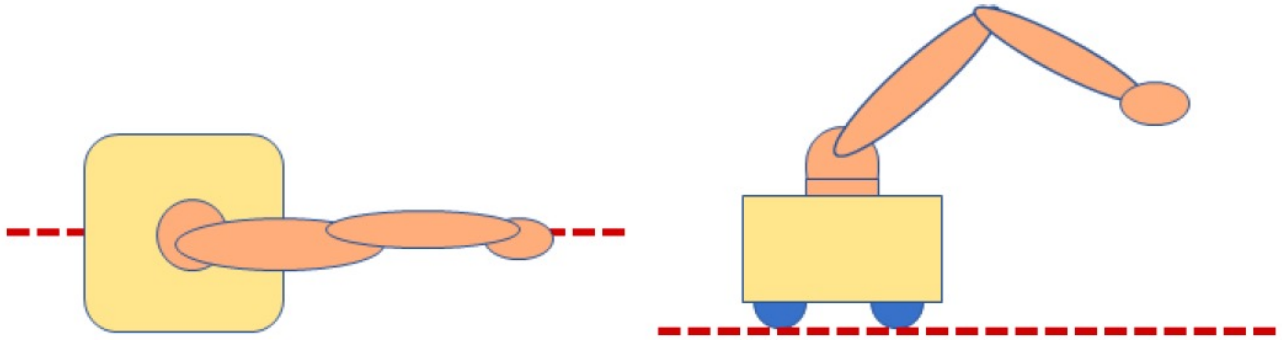

Figure B.3.ii.: Example of an IMR Type C, a mobile platform (in this case, an AGV), with a manipulator attachment.

(L: Plan View; R: Elevation View.)

ANSI/RIA R15.08

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- ISO 10218-1,2 개정 국제회의에 대응하기 위한 국내조직
  - 개정안 검토
  - 현안, 대응방안 논의
  - 한국로봇산업협회가 간사 역할 수행

- 국내 로봇전문가 그룹
  - 산학연
  - 로봇제조사, 로봇 SI 업체, 로봇/로봇시스템 인증기관

- 그 외 - 지능형로봇표준포럼

The end