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# Technology Readiness Level as an Exit Criteria of Early Life Cycle Phases for Steel-Making Plant

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# Outline

1. Research background & motivation
2. Research tasks (and content structure)
3. General systems: life-cycle, exit criteria, and TRL
4. **Steel-making plant: life-cycle, exit criteria, and TRL**
5. Conclusion



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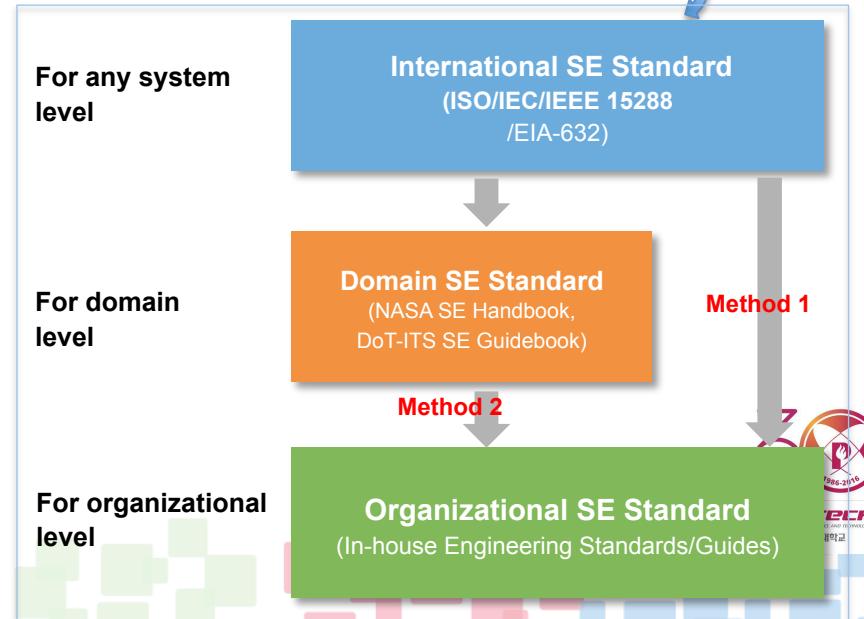
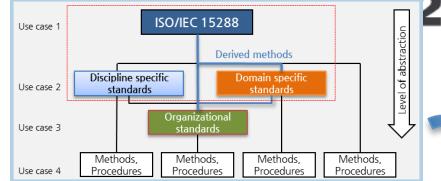
# 1. Research background

- Develop engineering guide for the steel-making plant domain.
- SE standard development methods overview
  - SE Standard development methods

From the concept of SE standard development methods, two methods are figured out as shown in the figure.

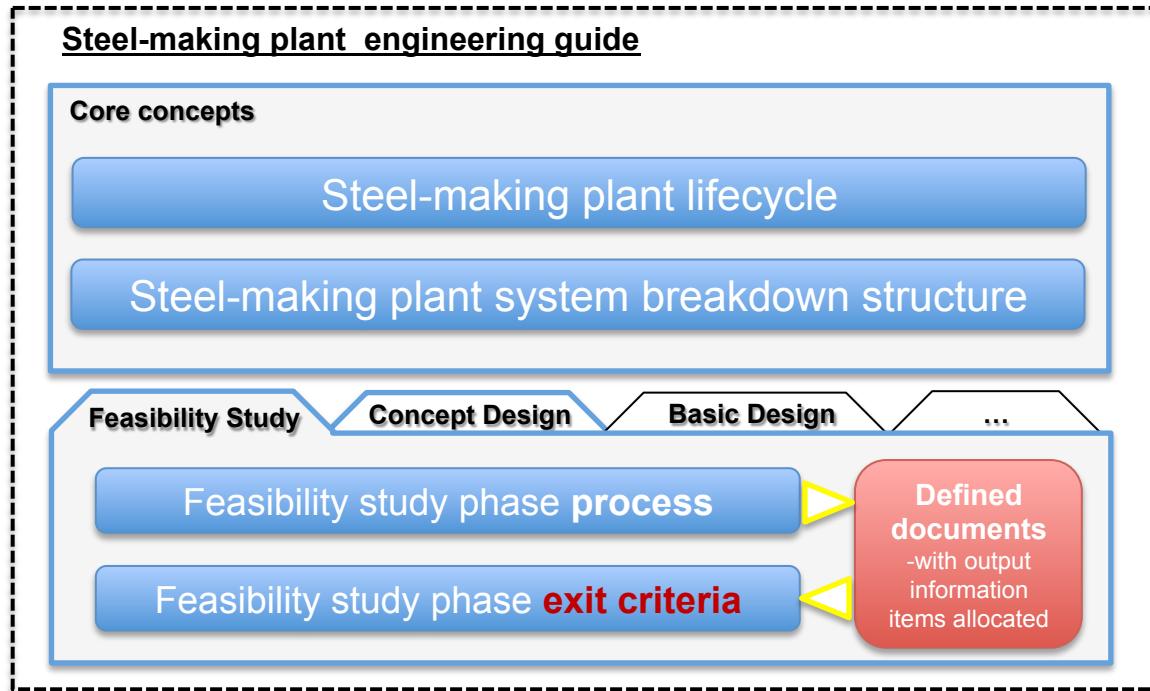
**Method 1 is to utilize international SE standards directly for an organization's business** through tailoring

**Method 2 is to develop an organizational standard from domain specific SE standards** which have been developed based on international SE standards



# 1. Research background

- Overall structure of the steel-making plant engineering guide



Developed

Future work

This figure shows the overall structure of the steel-making engineering guide

The engineering guide is made up of two main parts:

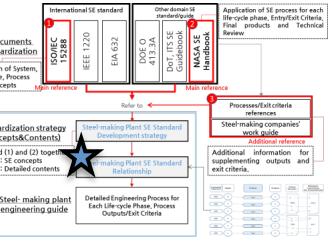
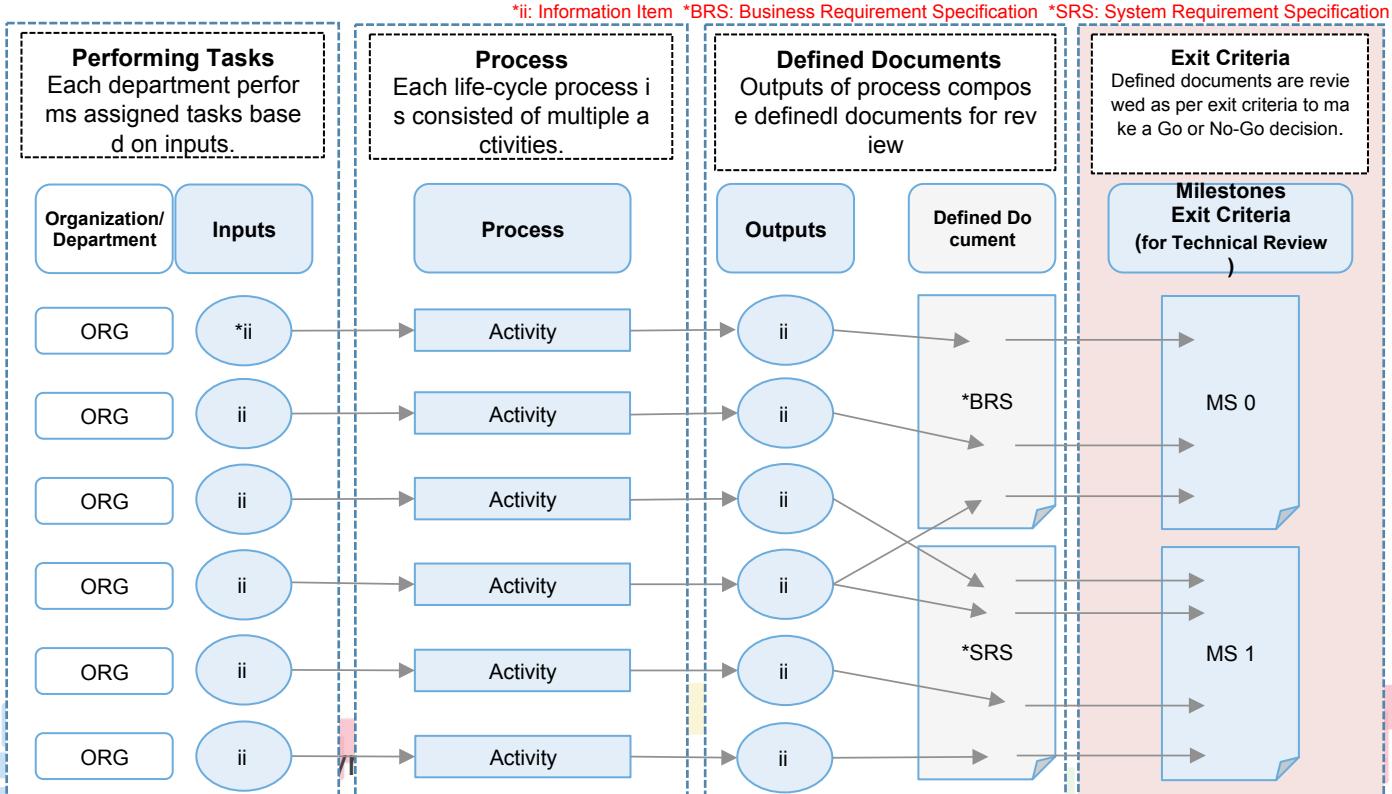
Core concepts and process/exit criteria for each lifecycle phase.

Blue boxed contents are within the scope of the paper: Feasibility study and concept design phases.



# 1. Research background

## ★ Steel-making Plant SE Guide Development Direction - Process vs. information item alignment



Relationship among the engineering guide elements are defined as shown in diag.

**Scope of this presentation**

**Done by the study**

**Future work**

**\*Note:** Only types/descriptions of defined documents are defined.



# 1. Research background

This paper is related with paper#206 titled:

## “Steel-making Plant Engineering Guide Development Based on Systems Engineering Standards: Feasibility Study and Concept Design”

- (Paper#206) The “Steel-making Plant Engineering Guide” provides core concepts, processes, outputs of processes and **exit criteria** for outputs.



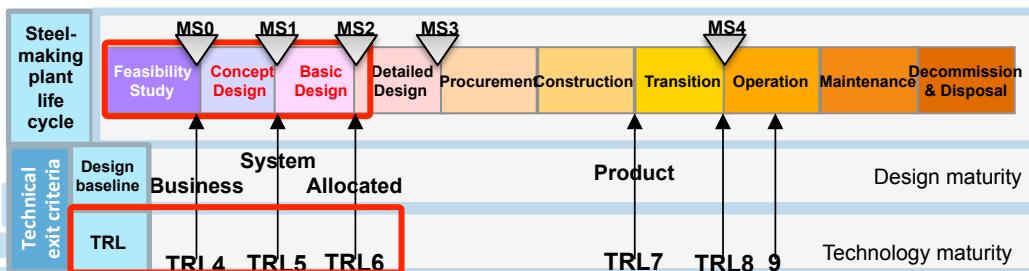
### Research goal

Reduce *steel-making plant* development project’s technology maturity risk by allocating target technology maturity, in terms of **TRL** (Technology Readiness Level), as an **exit criteria** to the life cycle phases

**Advantages** of target TRL assignment (directly) to life cycle phases: the **technical risk** of developing new technology or integrating additional technology to existing system is clear/easy to understand/analyze on each life cycle stage.

### Research outputs

1. Steel-making plant lifecycle (details included in paper#206)
2. Steel-making plant’s TRL definition
3. Steel-making plant’s target TRL assignment to lifecycle phases
4. TRL checklist for early lifecycle phases



Terminology:

Technical risk: risk caused by design maturity (risk) and technology maturity (risk)

Technology maturity risk: risk caused by technology maturity issues

Design maturity(progress) risk: risk caused by design maturity issues



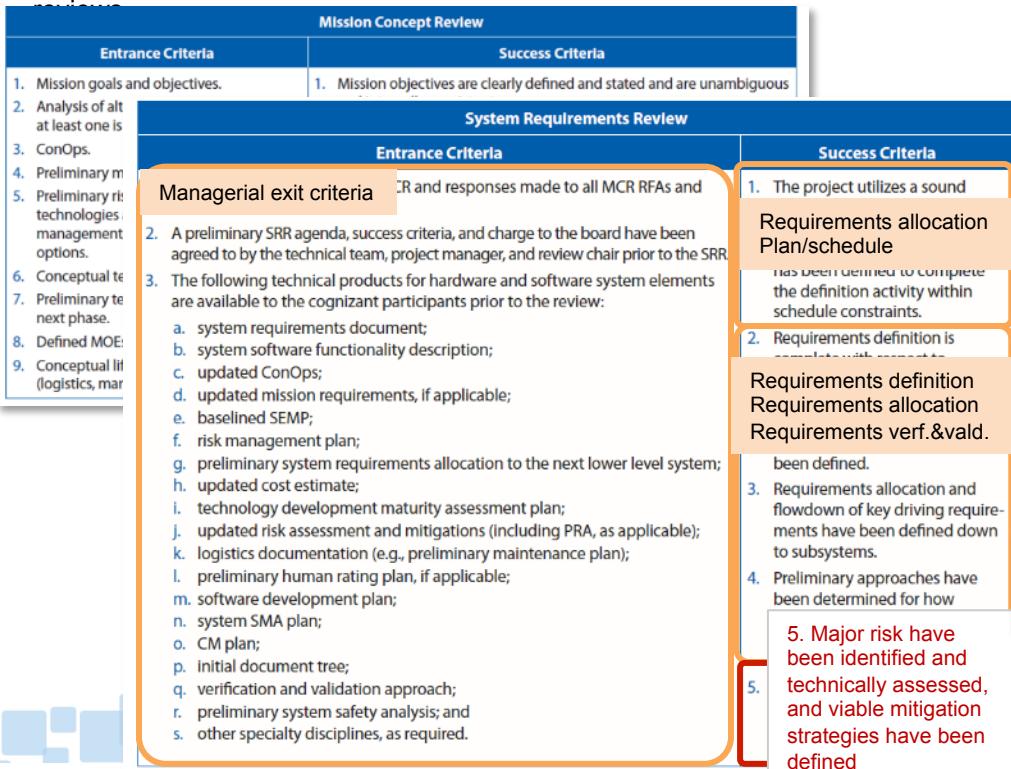
## 1. Research motivation



- References' exit criteria lacks "technology maturity" assessment

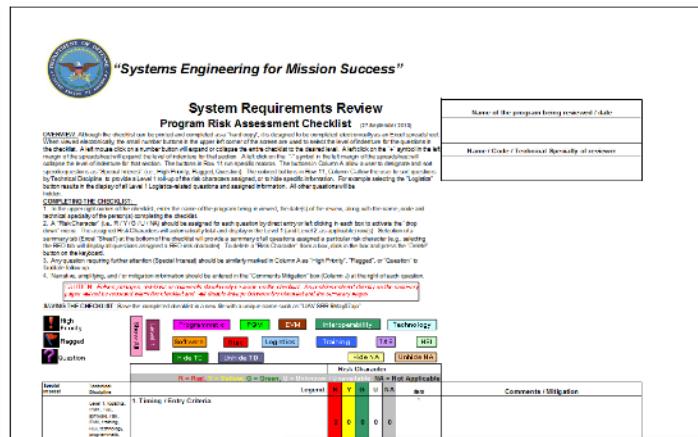
- **Example 1:** Life cycle phase's exit criteria are reflected as "Entrance Criteria" and "Success Criteria" of NASA's technical

- **Example 2:** Life cycle phase's exit criteria are reflected as "Program Risk Assessment Checklist" of DoD's technical reviews



\*Mission Concept Review (MCR) is conducted at the end of “Pre-Phase A:Concept Studies”

\*System Requirements Review (SRR) is conducted at the end of "Phase A: Concept & Technology Development"



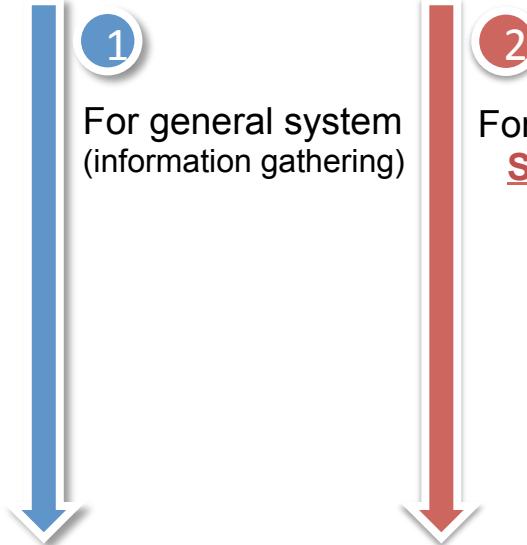
## Section

1. Timing/Entry Criteria
2. Planning
3. Program Schedule
4. Management Metrics (Cost, ...)
5. Program Staffing
6. Process Review
7. Product Support
8. System Requirements
- 9. Technology Development**
10. System Verification
11. Program Risk Assessment
12. Completion/Exit Criteria

## 2. Research tasks and content structure



- A. System life-cycle
  - Life-cycle phases
  - Each life-cycle phase's exit criteria
- B. Types of exit criteria
  - Economical
  - Societal
  - Technical: design maturity & technology maturity
- C. Technology Readiness Level (TRL)
  - TRL definition
  - TRL assignment to life cycle phases
  - TRL checklist

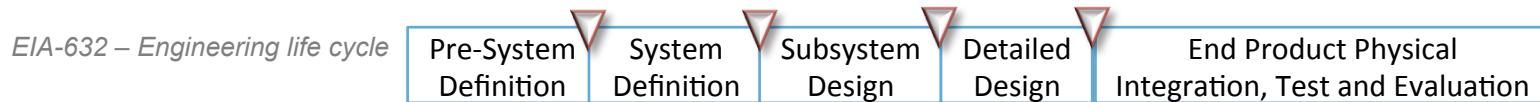


1  
For general system  
(information gathering)

2  
For application domain:  
Steel-making plant

### 3. General systems – engineering life cycle

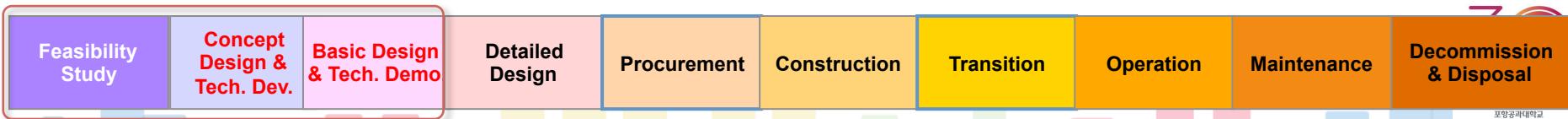
- Engineering life cycle properties (phases, processes, milestones/reviews, exit criteria)
- Different application domains can adopt different life cycle definition



#### Engineering life cycle properties:

- Life cycle phase:** a system's engineering life cycle consists of phases
- Formal review:** at the end of a phase, there is a formal review (milestone) to (1) evaluate the performance of the phase and (2) decide whether to continue to the next phase
- Exit criteria:** each phase has exit criteria to be fulfilled
- Processes:** each phase has processes that have to be performed to satisfy the phase's exit criteria
- Exit criteria checklist:** At a formal review, the fulfillment of each exit criteria statement (of the relevant phase) is examined/checked. Exit criteria checklists may support the formal review activities

#### (Proposed) Steel-making plant development system life cycle

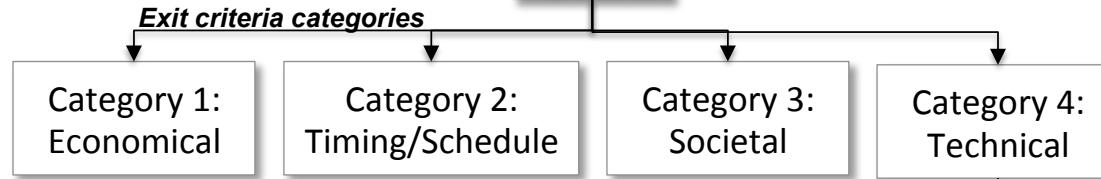




### 3. General systems – exit criteria

- Exit criteria properties and categories
- Technology maturity → TRL

Exit Criteria



This category created to support no overlap and no omission of the required information.

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#### Exit criteria properties

- Establishment of **general guideline/framework of exit criteria** for each life cycle phase is **important**
- Life cycle processes properties (purpose, outcomes, activities, and tasks) need to be aligned to exit criteria
- Under certain circumstances (e.g. project's special characteristics), the exit criteria **can be tailored**.

**4.1**

**Design maturity**  
= completeness of  
Sol's architecture  
definition

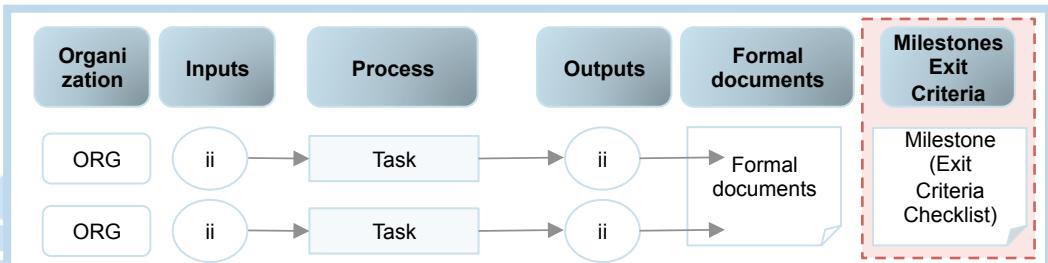
**4.2**

**Technology maturity**  
= readiness of the (critical) technology  
to be applied

**Measured by**

#### **Technology Readiness Level (TRL)**

TRL is a measurement (scale) of *technology maturity* to represent the technology's readiness to be realized/ implemented

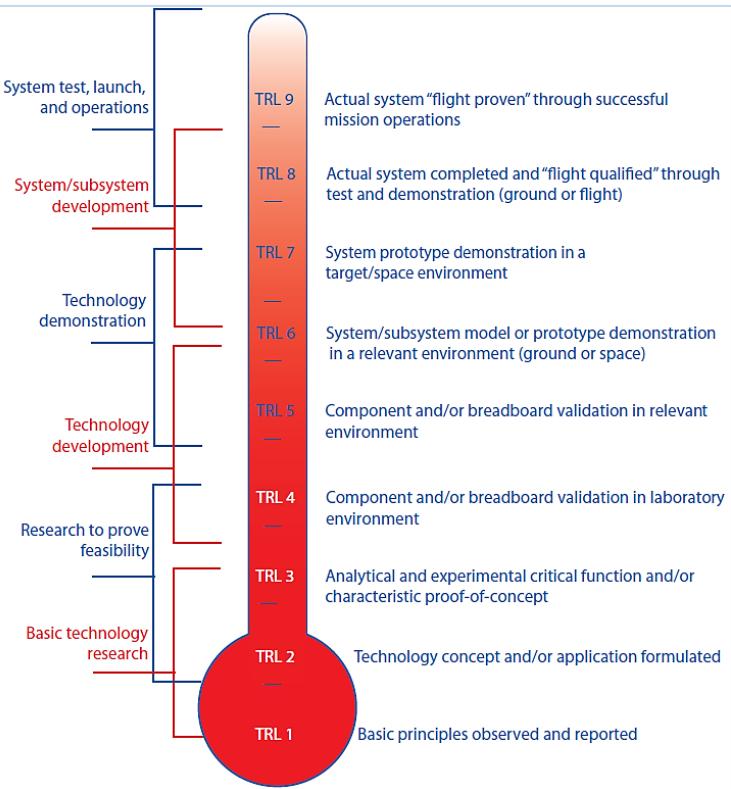




### 3. General systems – Technology Readiness Level (TRL)

- TRL definition by various organizations has similar properties

NASA's TRL



DoD's TRL

Table C-1. Hardware TRL Definitions, Descriptions, and Supporting Information

TRL	Definitions	Descriptions	Supporting Information
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied.	Published research that identifies the principles that underlie this technology. References to who, where, when.

DoE's TRL

Table 1. Technology Readiness Levels

Relative Level of Technical Development System Operation	Technology Readiness Level	TRL Definition	
		TRL 9	Description
Actual system operating under the full range of operating conditions.	The technology is in its final form and is operational under the full range of operating conditions. Examples include the actual system with the full range of modes in full operation.		
Actual system operating under the full range of operating conditions.	The technology is in its final form and is operational under the full range of operating conditions. Examples include the actual system with the full range of modes in full operation.		

Organizations that have defined TRL:

- National Aeronautics and Space Administration (NASA)
- United States Department of Defense (DoD)
- United States Department of Energy (DoE)
- European Space Agency (ESA)
- ISO 16290 Space systems - Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment
- ...

Organizations in South Korea:

- Defense Agency for Technology and Quality (DTaQ)
- Korea Institute of Energy Technology Evaluation and Planning (KETEP)
- Electronics and Telecommunications Research Institute (ETRI)
- Korea Agency for Infrastructure Technology Advancement (KAIA)
- ...

TRL definition of these organizations have similar properties:

- Consists of 9 levels
- Definition/description (concept) of each level is similar (with NASA's TRL)

# 3. General systems – Technology Readiness Level (TRL)

- TRL definition of industries may have different properties (compared to NASA's TRL), but the concept is similar

Industries may have different TRL definition:

- (Detailed) Domain-specific activities are included in the TRL definition
- However, the underlying **concept is similar**

API: American Petroleum Institute

AC: Automotive Council

**A** API's TRL definition (for subsea industry) combined the component/prototype validation in a lab and relevant environment.

EPC(Full scale Dev.) Phase

## 7. Target environment

Transition Phase

## 8. Target environment

Operation Phase

## 9. System operation

**B** AC's TRL definition has an additional level to ensure vehicle distribution geographically

**B**

NASA's TRL	API's TRL	AC's TRL	Boeing's TRL
<b>1. Basic principle</b>	TRL 0: Unproven Concept (Basic R&D, paper concept)	TRL 1: Basic Principles have been observed and reported	TRL 1: Basic principles/concept of test equipment and procedure defined.
<b>2. Technology formulation</b>	TRL 1: Proven Concept (As a paper study or R&D experiments)	TRL 2: Speculative applications have been identified	TRL 2: Test method concept formulated and defined by draft standards
<b>3. Concept proof</b> Feasibility Study Phase	TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept	TRL 3: Analytical and experimental assessments have identified critical functionality and/or characteristics.	TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept (e.g. by modifying old/existing equipment)
<b>4. Lab. validation at component level</b> Tech. Dev. Phase	TRL 4: Component and/or breadboard validation (component level)	TRL 3: Prototype Tested (System function, performance and reliability tested)	TRL 4: The technology component and/or basic subsystem have been validated in the laboratory or <b>test house environment</b>
<b>5. Relevant environment validation at component level</b> Tech. Demo. Phase	TRL 5: Component and/or breadboard validation (relevant environment)		TRL 5: The technology component and/or basic subsystem have been validated in relevant environment, potentially through a multi or adapted current <b>production vehicle</b> .
<b>6. Relevant environment validation at system level</b> EPC(Full scale Dev.) Phase	TRL 6: System/subsystem model or prototype demonstration in a relevant environment	TRL 4: Environment Tested (Pre production system environment tested)	TRL 6: A model or prototype of the technology system or subsystem has been demonstrated as part of a <b>vehicle</b> that can simulate and validate all system specifications within a test house, test track or similar operational environment.
<b>7. Target environment</b> Transition Phase	TRL 7: System prototype demonstration in a space environment	TRL 5: System Tested (Production system interface tested)	TRL 7: <b>Multiple prototypes</b> have been demonstrated in an operational, <b>on-vehicle</b> environment.
<b>8. Target environment</b> Operation Phase	TRL 8: Actual system completed and "flight qualified" through test and demonstration (ground or space)	TRL 6: System Installed (Production system installed and tested)	TRL 8: Final test equipment drawings released, equipment built to the standards, and "qualified" through test and demonstration. Documented test guidance finalized.
<b>9. System operation</b>	TRL 9: Actual system "flight proven" through successful mission operations	TRL 7: Field Proven (Production system field proven)	TRL 9: <b>Multiple production units</b> verified by successful round robin testing.
			TRL 10: The technology is successfully in service in multiple application forms, vehicle platforms and geographic regions.



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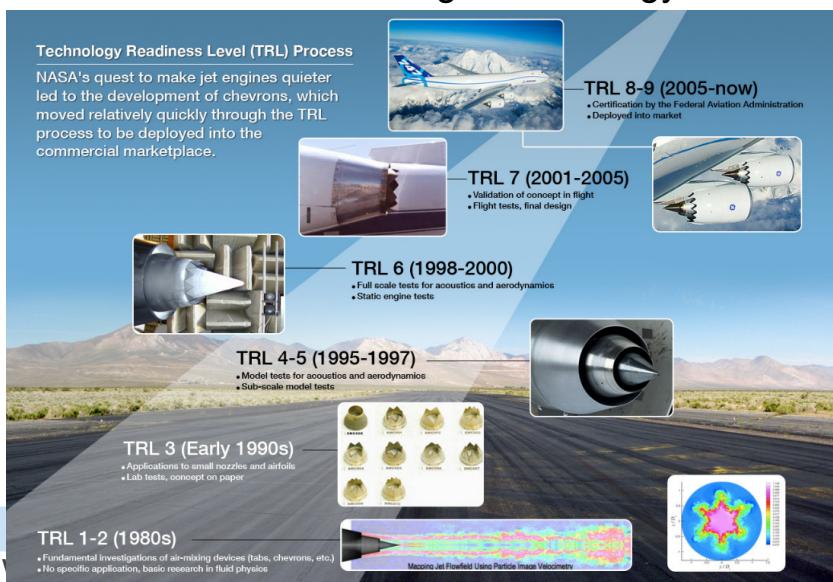
### 3. General systems – Technology Readiness Level (TRL)

- TRL usability - why the organizations/industries defined TRL

TRL is used to measure technology maturity. Technology maturity assessment is performed to:

1. Create and assess a certain **technology development stages (roadmap)**
2. Control a project's bidding condition (e.g. only bidders that can start the project from TRL 4 can bid)
3. Report the status of a technology development, and other usage
4. **Be an exit criteria of life cycle phase → however, usually TRL is not considered as one of the exit criteria**

Reference case of TRL usage: technology dev. roadmap



In this research, we propose target TRL assignment as an exit criteria to each steel-making plant's life cycle phases

Advantages of target TRL assignment (directly) to life cycle phases:

- The **technical risk** of developing new technology or integrating additional technology to existing system is **clear/easy to understand**/analyze on each life cycle stage



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# 3. General systems –TRL assignment

- Existing work on “target TRL allocation to life cycle phases”

DoD, 2014

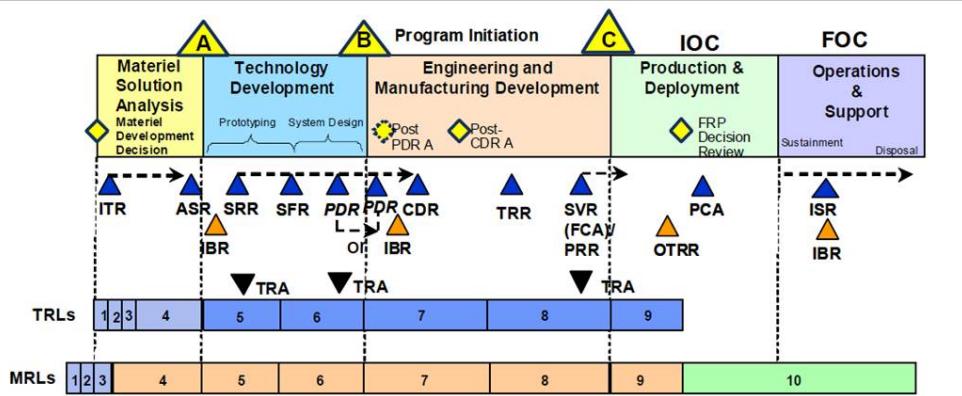
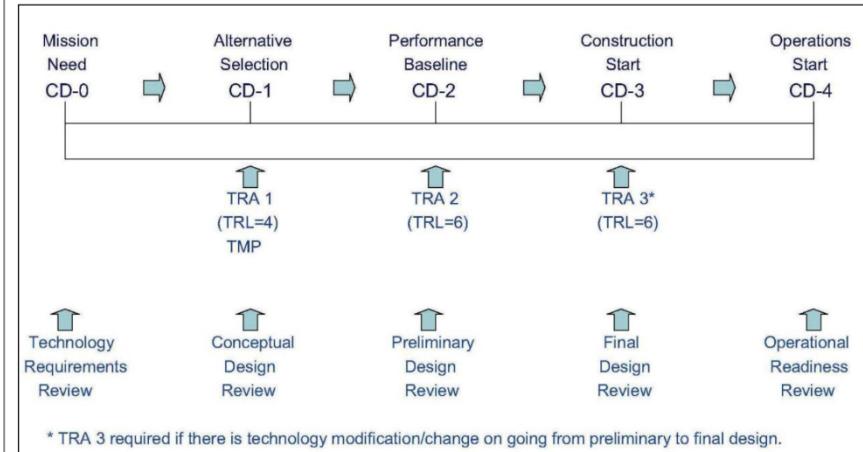


Figure 2. TRA Relationship to Systems Acquisition Gates, Milestones, and Events

DoE, 2011



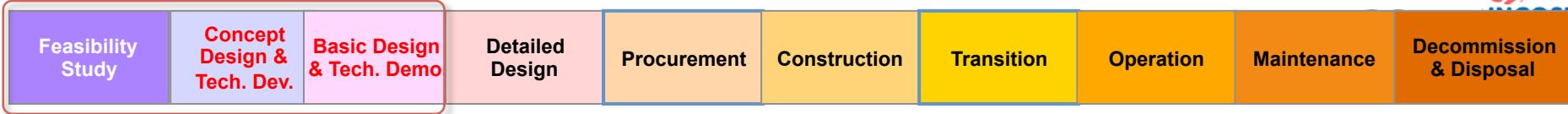
In this research, we

- propose a steel-making plant system life cycle,
- define the technical readiness level (TRL) for a steel-making plant,
- assign a target TRL for each life cycle stage as an exit criteria of that stage, and
- develop TRL checklists for early life cycle stages

# 4. Steel-making plant – system life cycle



- Steel-making plant life cycle definition



- Feasibility study stage:** wide spectrum of ideas and alternatives are developed while deciding the tasks of a new development project.
- Concept design and technology development:** the objectives are two-fold: (1) to determine the feasibility and desirability of the alternatives proposed at feasibility study stage and (2) to establish the compatibility/alignment between the organization's/enterprise's strategic plan and preliminary system baseline.
- Basic design and technology demonstration:** system and subsystem design specifications are completed and they are decided based on the preliminary performance requirements of the system. Also, the technical requirements are defined in a certain level of details to allow the prediction on project's schedule and cost.
- Detailed design:** detailed design (design drawings), hardware fabrication, and software coding of the system and subsystem (including the operational system) are completed.
- Procurement:** procurement is performed to realize the system. The procurement activities should consider the quality, cost, and delivery aspects in order to realize the system safely.
- Construction and installation:** practical system validation, realization, and verification take place.
- Transition:** The activities in the transition stage depends on the delivery agreement of integrated and verified end products to the system acquirer. Based on the contract, the supplier might have to install the verified system including the supporting systems, such as operator training, on the intended operational environment. (Commissioning is an important activity in steel-making plant)
- Operation:** the system is operating and performing its operational objectives in the intended environment.
- Maintenance:** the system is maintained/supported to enable continuous operation.
- Decommission and disposal:** the system and its related services are decommissioned. In this stage, system engineering activities mainly concern with the validation of disposal requirements fulfillment.



# 4. Steel-making plant – TRL definition

- Steel-making plant TRL definition

## Considerations in defining TRL for steel-making plant:

- References from other organizations/ industries' TRL definition
- Main technology viewpoints of a steel-making plant:
  - Material technology** (high-valued steel product material specifications)
  - Steel-making process design technology**
  - Steel-making facilities design technology**
  - Steel-making facilities operation technology**

Assessment scope of steel-making plant tech.

Assessment focus technology

TRL	Level name	Description
TRL 1	Technology <b>principle understanding</b>	The basic principles of the <b>material technologies, steel-making processes' technologies, and steel-making facilities' technologies</b> are understood.
TRL 2	Technology <b>application concept identification/ definition</b>	Contribution methods (application concept) of the material technologies, steel-making processes' technologies, and steel-making facilities' technologies to the end-products(steel products) are identified. Namely, technology concept development and application areas are identified.
TRL 3	<b>Analytical verification</b> of the technology application concept	Analysis/experiment on the core function of the identified technology related to the material, steel-making processes, and steel-making facilities. Or concept verification of the technology's characteristics
TRL 4	<b>Components performance verification in the laboratory environment</b>	Verification of the components or the required performance (laboratory-wise) of the core function of the identified technology related to the material, steel-making processes, and steel-making facilities in the laboratory environment
TRL 5	<b>Components performance verification in the similar operating environment</b>	Verification of the required performance (components-wise) of the core function of the identified technology related to the material, steel-making processes, and steel-making facilities in the environment similar with the operating environment
TRL 6	<b>System level performance verification in the similar operating environment</b>	Demonstration the (equipment-wise) model or prototype performance of the core function of the identified technology related to the material, steel-making processes, and steel-making facilities in the environment similar with the operating environment
TRL 7	Performance <b>demonstration</b> trial of the <b>prototype</b> in the actual <b>operating environment</b>	Demonstration the equipment prototype performance of the steel-making equipment in the operating environment
TRL 8	<b>Demonstration</b> of complete operation preparation of the <b>actual system</b> in the actual <b>operating environment</b>	Completion of equipment development and technology demonstration
TRL 9	Business operation	Operation of the equipment



# 4. Steel-making plant – TRL assignment

## • Steel-making plant TRL assignment

## Proposed life cycle phase and TRL assignment

### Considerations in assigning TRL to the life cycle phases of steel-making plant:

- From TRL definition etc.
  - Technology verification level
  - Technology verification environment
  - Technology verification methods

### TRL assignment characteristics

- This generic TRL mapping to the life cycle stages **may be tailored according to the project environment.**

Life cycle	TRL	V. Level	V. Env.	V. Method
Feasibility Study	TRL 4	Comp.	Lab.	M
Concept design and technology development	TRL 5	Comp.	Ref.	M, P
Basic design and technology demonstration	TRL 6	System	Ref.	P, D
Detailed design, Procurement, construction and installation	TRL 7	System	Op.	D, C
Transition	TRL 8	System	Op.	C
Operation and maintenance	TRL 9	System	Op.	C
Decommission and disposal	N/A	N/A	N/A	N/A

### Legend:

V. Level: Represent Component vs. System verification level

V. Env.: Represent laboratory, reference and operational environment.

V. Method acronyms: **M:** Modeling, **P:** Prototyping, **D:** Demonstration, **C:** Commercial plant verification

### DoD's & DoE's life cycle phase and TRL assignment – *for comparison*

DoD life cycle phases	TRL	DoE life cycle phases	TRL
Materiel solution analysis	TRL 4	Mission need	TRL 4
Technology development	TRL 5	Alternative selection	TRL 6
Engineering and manufacturing development	TRL 8	Construction start	TRL 6
Production and deployment	TRL 9	Operations start	N/A

## 4. Steel-making plant – TRL assignment



- TRL checklist

## **Considerations in developing TRL checklist**

- Definition of steel-making plant's TRL
  - Each level of TRL has some required verification methods
- Steel-making plant's life cycle phase, process, and exit criteria definition
  - Each phase of life cycle has process verification/validation requirement
- References from other organizations/industries' TRL definition

## Proposed life cycle phase and TRL assignment

Life cycle	TRL	Method
Feasibility Study	TRL 4	M
Concept design and technology development	TRL 5	M, P
Basic design and technology demonstration	TRL 6	P, D
Detailed design, Procurement, construction and installation	TRL 7	D
Transition	TRL 8	C
Operation and maintenance	TRL 9	C
Decommission and disposal	N/A	N/A

Legend:  
Method acronyms: M: Modeling, P: P  
C: Commercial verification

No	Case Category	Description
1	Target (B) breakdown	The target breakdown structure (BBS) has been defined, but the target is not yet defined or not yet applied to the target breakdown structure.
2	TRM assessment	The target and the breakdown of the TRM assessment are defined.
3	Target (B) definition	Target (B) has been defined. It is, though, the target breakdown structure (BBS) that is used.
4	The behavior's characteristics	The target characteristics are known and used.
5	Target (B) and target characteristics definition	TRM theory of the project manager defines the target and the target characteristics.
6	The behavior's characteristics	The target characteristics are known and the target breakdown structure (BBS) has been defined.
7	Operational measurement	The current operational measurement based on the target breakdown structure (BBS) is used.
8	Latency measurement	The current latency measurement, including the reliability of the target breakdown structure (BBS), is used.
9	Target (B) requirements	The target (B) requirements have been defined, but the target breakdown structure (BBS) has not been defined.
10	Goal definition - A	The methods are appropriate to validate the target breakdown structure (BBS).
11	Goal definition - C	The methods of the model used in the laboratory are not appropriate for the model of the target.
12	Goal definition - Preference	The target breakdown structure (BBS) is preferred.
13	Goal definition - No preference	The target breakdown structure (BBS) has not been preferred.

TRL 6

TRL 5

## TRL 4 checklist

## TRL 9 checklist

## TRL 8 checklist

## TRL 7 checklist

### TRI 3 checklist

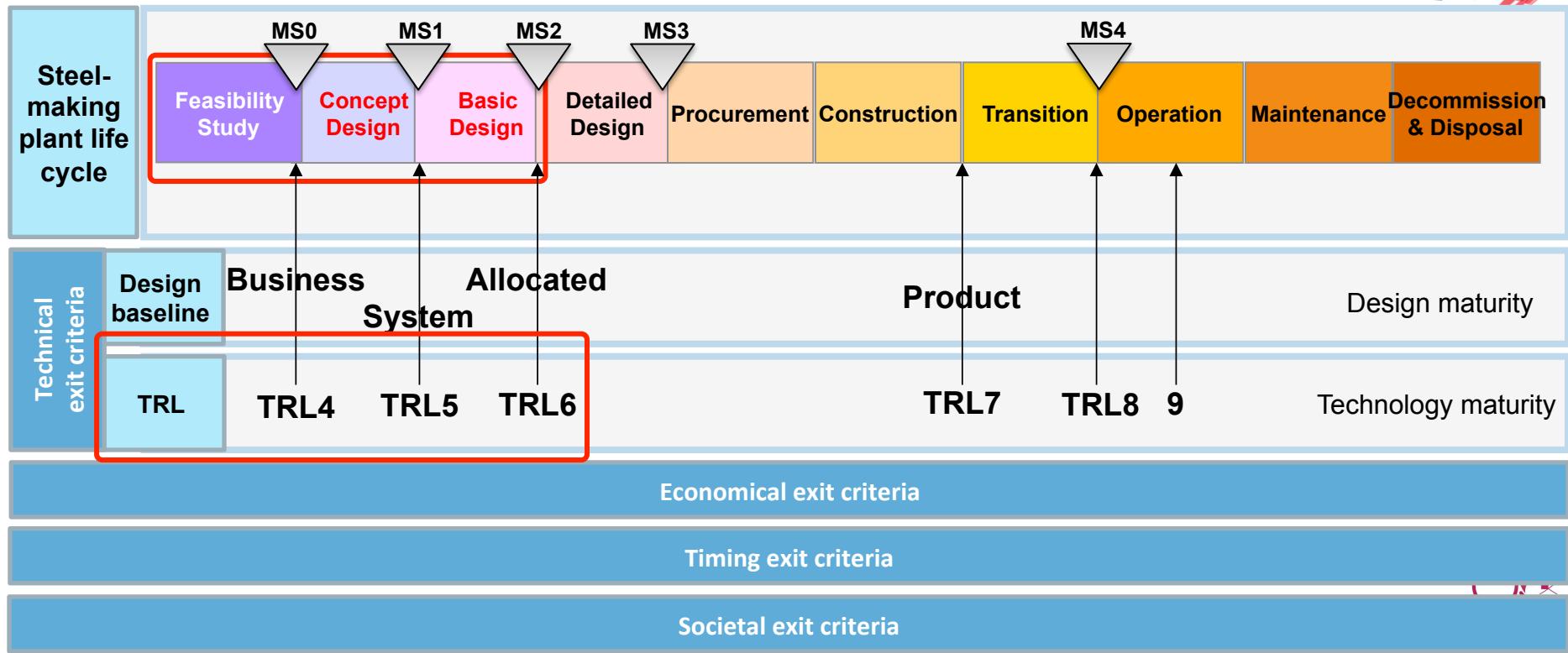
TRL 2 chec

### TRE 1 checklist



# 4. Steel-making plant – TRL exit criteria

- Steel-making plant life cycle phases' exit criteria

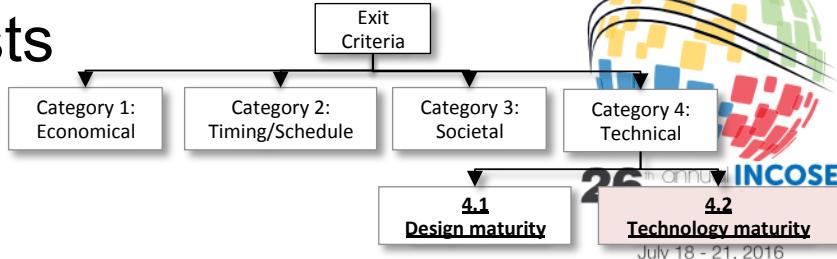


# 4. Steel-making plant – TRL checklists

- Case study: solution

## Exit criteria checklist structure

Section	Sub-section
<b>A. REVIEW MEMBERS AND REVIEW DOCUMENTS EVALUATION</b>	
	A.1 Review members
	A.2 Review documents preparation
<b>B. PROJECT OVERVIEW AND GOAL EVALUATION</b>	
	B.1 Project overview
	B.2 Specification tree and system specification
<b>C. DESIGN PROGRESS EVALUATION</b>	
	C.1 Stakeholder requirements
	C.2 System requirements
	C.3 Specialty engineering requirements
	C.4 System architecture
	C.5 Measurements (MoE, MoP)
	C.6 Verification and validation requirements
	C.7 Requirements traceability
<b>D. TECHNOLOGY MATURITY EVALUATION</b>	
	D.1 TRL
<b>E. ENGINEERING PLAN EVALUATION</b>	
	E.1 System Engineering Management Plan (SEMP)
	E.2 Schedule
	E.3 Modeling & simulation plan
<b>F. PROJECT LIFE CYCLE COST ESTIMATION EVALUATION</b>	
	F.1 Cost estimation
<b>G. RISK EVALUATION AND STATUS</b>	
	G.1 Risk evaluation
	G.2 Risk status



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TRL 6 checklist (for BD exit criteria 147 ea.)

TRL 5 checklist (for CD exit criteria 100 ea.)

TRL 4 checklist (for FS exit criteria 84 ea.)

No	Exit Criteria	Description	and software	has been written
1	Physical Breakdown Structure (PBS) development	Physical Breakdown Structure (PBS) has been developed for the target technology that will be applied	System	The feasibility of the integrated logical model and each logical module of the identified software's functions has been presented
2	TRL measurement definition	The term and description of the TRL measurement of the target technology has been defined		
3	Target TRL definition	Target TRL has been defined. For example, the target TRL of Feasibility Study (FS) phase is TRL 4. Target TRL can be changed depending on the business project		
4	The technology's characteristics definition	The characteristics of the intended technology have been defined. These characteristics are sorted and used in TRL definition		
5	The technology's characteristics definition – TRL measurement metrics	The measurement metrics, in order to determine the TRL maturity of the previously defined target technology, have been decided. These metrics are also called TRL measurements		
6	The technology's characteristics definition – TRL measurement methods	The decision method of the previously defined TRL measurement's values have determined		
7	Operational environment definition	The system's operational environment based on operational scenario has been defined		
8	Laboratory environment definition	The laboratory environment where the technology will be tested has been defined to match the defined operational environment		
9	Laboratory test requirements definition	The test requirements have been defined to enable the system requirements test in the laboratory level		
10	Test definition – Goal	The test methods are appropriate to validate the technology's feasibility		
11	Test definition – Component	The components of the model used in the laboratory level are substitute of the components of the target system		
12	Test definition – Performance target	The test target values that replicate the performance target of the system have been defined		
13	Test definition – Performance measurement	The system performance measurement unit has been defined		
14	Test preparation – Algorithm	Algorithm – The algorithm's pseudo code of the systems		
			Supplier	The interfaces between the related components of the technology (which its realization possibility is not yet validated) has been demonstrated in laboratory scale by means of simulation
			Supplier	The supplier has demonstrated each component of the system (acquire components' acceptance test). * This item is an optional exit criteria of Feasibility Study (FS) stage
			Supplier	Analysis about the performance test result in the laboratory environment has been completed. This analysis result validated the defined performance requirements (of the task analysis)
			Supplier	The basic functions of the target technology have been validated in the laboratory scale through the technology demonstration
			Supplier	The components' compatibility has been validated * This item is an optional exit criteria of Feasibility Study (FS) stage
			Supplier	The target technology's realization has been validated in the laboratory environment
			Supplier	The scale-up relation of the technology has been understood and considered in the technology development * This item is an optional exit criteria of Feasibility Study (FS) stage

# TRL 4 Checklist



## Steel-making plant TRL 4: Components performance verification in the laboratory environment

No	Exit Criteria	Description
1	Physical Breakdown Structure (PBS) development	Physical Breakdown Structure (PBS) has been developed for the target technology that will be applied to the system.
2	TRL measurement definition	The term and description of the TRL measurement of the target technology has been defined.
3	Target TRL definition	Target TRL has been defined. For example, the target TRL of Feasibility Study (FS) phase is TRL 4. Target TRL can be changed depending on the business/project.
4	The technology's characteristics definition	The characteristics of the intended technology have been defined. These characteristics are sorted and used in TRL decision.
5	The technology's characteristics definition – TRL measurement metrics	The measurement metrics, in order to determine the TRL-maturity of the previously defined target technology, have been defined. These metrics are also called TRL measurements.
6	The technology's characteristics definition – TRL measurement methods	The decision method of the previously defined TRL measurements' values have determined.
7	Operational environment definition	The system's operational environment based on the <a href="#">Operational environment definition</a> has been determined.
8	Laboratory environment definition	The laboratory environment where the technology will be tested has been defined to imitate the <a href="#">operational environment</a> .
9	Laboratory test requirements definition	The test requirements have been defined to enable the system requirements test at the laboratory level.
10	Test definition – Goal	The test methods are appropriate to validate the technology's feasibility.
11	Test definition – Component	The components of the model used in the laboratory level are substitute of the components of the target system.
12	Test definition – Performance target	The test target values that replicate the performance target of the system have been defined.
13	Test definition – Performance measurement	The system performance measurement unit has been defined.
14	Test preparation – Algorithm	Algorithm – the algorithm's pseudo code of the systems

and software	has been written. Software – The feasibility of the integrated logical model and each logical module of the identified software's functions has been presented.
5 Test demonstration – Component	Necessary performance validation of the component performance of the technology (which its realization possibility is not yet validated) has been demonstrated in laboratory scale.
6 Test demonstration – Multiple components	The subsystems technology (which its realization possibility is not yet validated) that is composed of multiple components has been demonstrated in laboratory scale by means of simulation.
7 Test demonstration – Interface	The interfaces between the related-components of the technology (which its realization possibility is not yet validated) has been demonstrated in laboratory scale.
8 Test demonstration – Supplier	The supplier has demonstrated each component in laboratory scale (acquirer components' acceptance test).
8	Laboratory environment definition
9	Test results verification – demonstration
10	The components' compatibility has been validated.
11	Test definition – Component

15	Test demonstration – Component	<p>Necessary performance validation of the component performance of the technology (which its realization possibility is not yet validated) has been demonstrated in laboratory scale.</p>
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		의상보조 전달되었다.
A.1.2	사업 타당성 검토위원회 참여자 선임	사업 타당성 검토회(Business Feasibility Review, BFR)의 진행에 필요한 사람들이 적합하게 선임되었다.
A.1.3	해당 기술 전문가 참여 확인	사업 타당성 검토회(Business Feasibility Review, BFR)의 목적에 적합한 기술 전문가들이 검토회에 참여하였다.
A.1.4	이해관계자 참여 확인	이해관계자 또는 이해관계자들의 대리인이 적절한 권한을 가지고 사업 타당성 검토회(Business Feasibility Review, BFR)에 참여하였다.

8	Laboratory environment definition	The laboratory environment where the technology will be tested has been defined to imitate the defined operational environment
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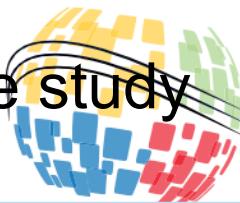
The components of the model used in the laboratory		Level are substitute of the components of the target
A.2.3	타당성검토 보고서(FAR) 작성	타당성 검토(Feasibility Study, FS) 프로세스를 성공적으로 수행하여 타당성검토 보고서(Feasibility Analysis Report)를 완성하여 제출하는 과정

11	Test definition – Component	The components of the model used in the laboratory level are substitute of the components of the target system.
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	<p>*사업 규모를 문장으로 기술하고 아래에 따른 사업 규모를 개도로 구체화하여 표준문서로써 사업 목적이 완료하지 않고 쉽게 이해할 수 있도록 표기한다. - “<u>上讀即解</u>”</p> <p>*<u>첨조 정보</u>: 분석이 필요하고 가능한 경우 다음 항목을 적용;</p> <p>- 전략·연관성: <i>Vision 2020</i>, 중기전략, 실행계획 실행계획과의 정합성</p> <p>(참조: 혈강 프로젝트 성 투자 업무지침·부록 1. Risk 점검 Check List [투자관리규정 첨부 3.])</p>
<b>B.2 사업/프로젝트 범위 검토</b>	<p><b>B.2.1</b> 사업/프로젝트 범위 정의</p> <p>사업 범위를 명확하게 정의하였다.</p> <p>*문용어점의 외부체계와 인터페이스를 고려한 사업범위 표현과, 생생주기 지원체계를 고려한 사업범위를 명확히 표현하였다.</p> <p>*<u>첨조 정보</u>: 분석이 필요하고 가능한 경우 다음 항목을 적용;</p> <p>- 생선 규모의 적정성·초년도 및 연도별 생산계획의 적정성(생선 근거) - 고기·어장의 저점·서·도입기·전망·인력 대비·자원·환경·법률·국제화·부록 1. 표준문서</p>

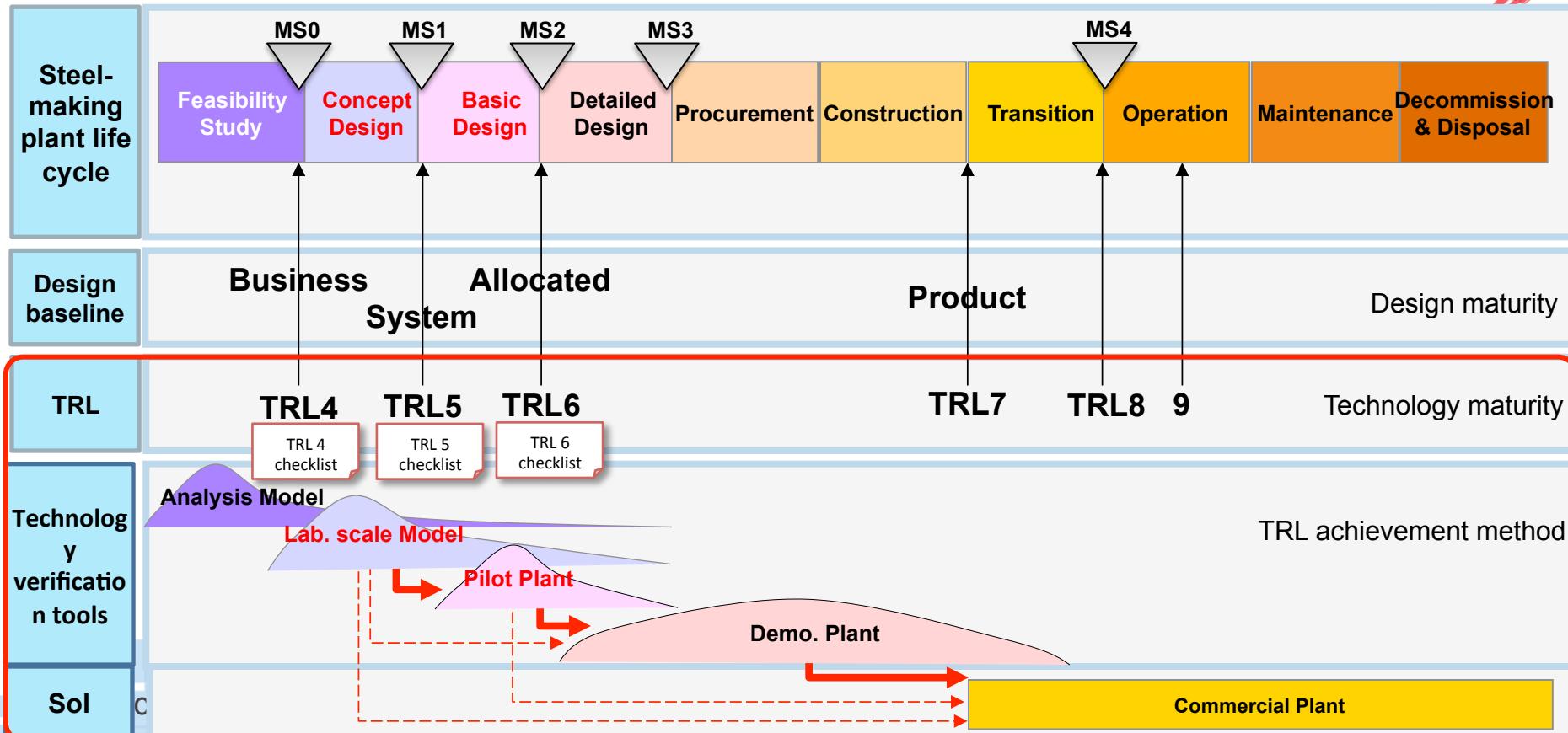
The original research results are in Korean language.

The authors translated the checklist from Korean language to English.



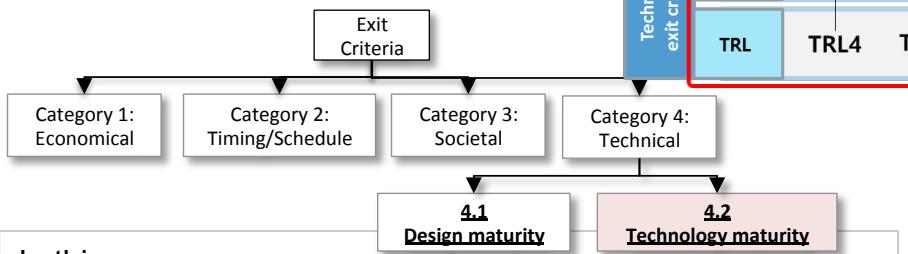
## 4. Steel-making plant – Life cycle & TRL assignment case study

- Case study: solution - integrated



# 5. Conclusion

*Paper title: Technology Readiness Level as an Exit Criteria of Early Life Cycle Phases for Steel-Making Plant*

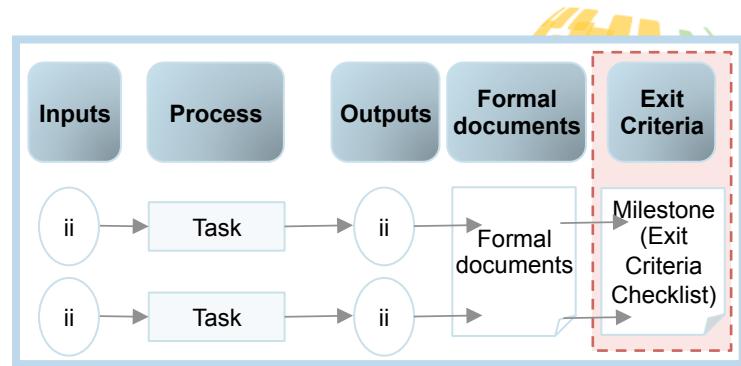


In this paper, we propose

1. Steel-making plant lifecycle phases\*
2. Steel-making plant's TRL definition
3. Steel-making plant's target TRL assignment to lifecycle phases
4. TRL checklist for early lifecycle phases

Advantages of target TRL assignment (directly) to life cycle phases:

- The **technical risk** of developing new technology or integrating additional technology to existing system is clear/easy to understand/analyze on each life cycle stage.
- The technology development effort could be aligned with the information items within the checklist



## Lessons learned

- Life cycle processes properties (purpose, outcomes, activities, and tasks) need to be aligned to exit criteria
- Exit criteria should include economical, timing/schedule, societal, and technical exit criteria. Technical exit criteria should include design maturity and **technology maturity**.
- The key to the world steel market is to develop new technologies that are able to produce **high value-added steel products**. However, new technologies have **high technical risk**. To solve the technical risk, target TRL should be included as an exit criteria of each steel-making plant life cycle

# THANK YOU

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This research was also supported partly by POSCO.





# 4. Case study – Life cycle & TRL assignment

## • Case study: problem

A steel-making plant applies the concept of “Analysis model, lab scale model, pilot plant, demonstration plant, commercial plant” as its engineering development stage instead of engineering life cycle phases.

- However, “**Analysis model, lab scale model, pilot plant, demonstration plant, commercial plant**” is **supporting methods**, thus should not be applied as “life cycle phases”
- Problems occurred by using “supporting models” as life cycle phases:
  - The objective of the formal review at the end of each phase is not to evaluate (technical) risks but whether the model has been built/completed or not.
  - The design/development engineers do not have clear goals of building the models(**kinds of technology to be verified, verification methods needed, etc, are vague**) but rather only to finish the models.
  - When the models or final product (commercial plant) fails, the developers can not analyze the root cause.

Proposed life cycle phase and TRL assignment

Life cycle	TRL	Method
Feasibility Study	TRL 4	M
Concept design and technology development	TRL 5	M, P
Basic design and technology demonstration	TRL 6	P, D
Detailed design	TRL 7	D
Procurement, construction and installation	TRL 7	D
Transition	TRL 8	C
Operation and maintenance	TRL 9	C
Decommission and disposal	N/A	N/A

Legend:

Method acronyms: M: Modeling, P: Prototyping, D: Demonstration, C: Commercial verification



# 4. Case study – Life cycle & TRL assignment

- **Case study: solution**

- Proposed solution
  - Development stage should use “**life cycle phases**”
    - ✓ Delivered product: Life cycle definition
  - Each life cycle phase should have **exit criteria**. At the end of each phase, a technical/formal review should be held to evaluate the fulfillment of exit criteria
    - ✓ Delivered products (4):
      1. Feasibility study phase exit criteria checklist,
      2. Concept design and technology development exit criteria checklist,
      3. Basic design and technology demonstration exit criteria checklist
      4. Detailed design exit criteria checklist
  - The “Analysis model, lab scale model, pilot plant, demonstration plant, commercial plant” concept understanding is redirected as **TRL achievement method** (life cycle supporting method)
    - ✓ Delivered product: Life cycle and TRL assignment

Proposed life cycle phase and TRL assignment

Life cycle	TRL	Method
Feasibility Study	TRL 4	M
Concept design and technology development	TRL 5	M, P
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