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SE approach to ubiquitous maintenance system design - Requirements development methodology

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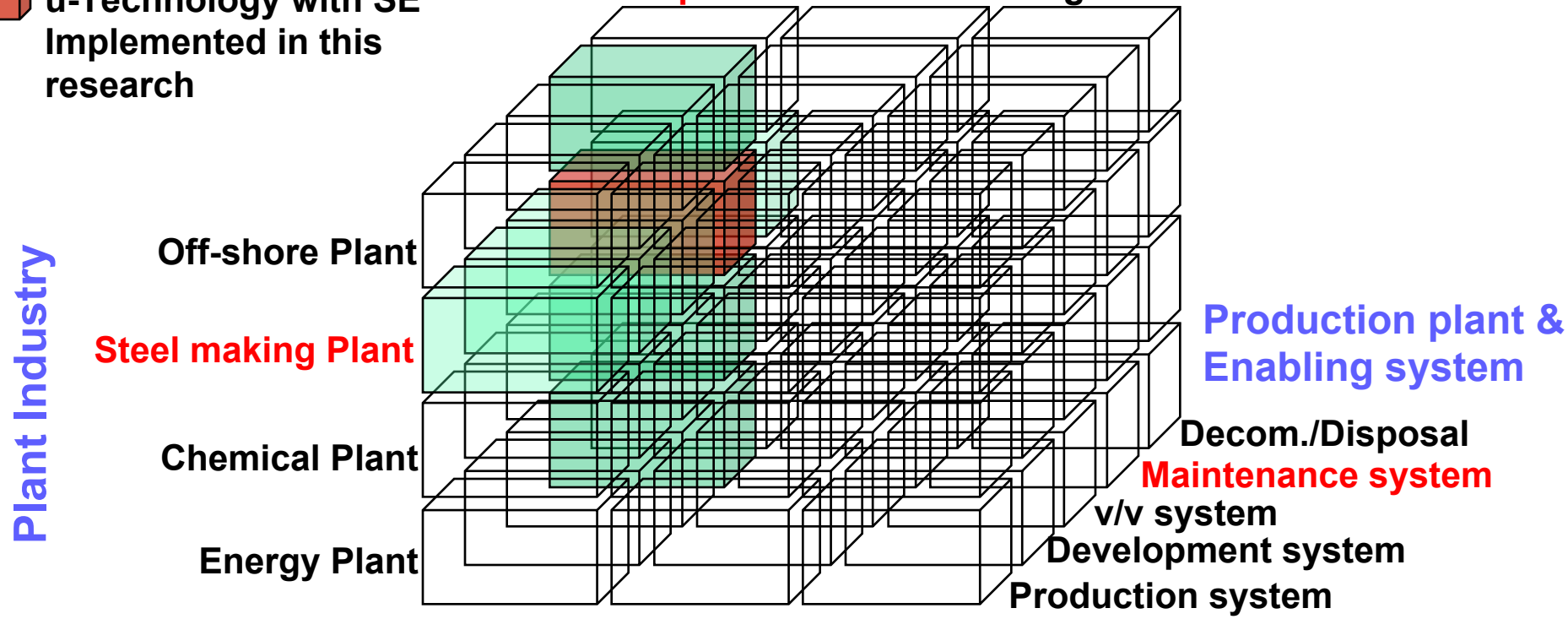
Contents

1. Introduction

Scope & Intent

- Demonstrate SE application to the Plant industry.
- Demonstrate capability enhancing mechanism via adoption of new technology, l ike ubiquitous technology.

u-Technology with SE Implemented in this research



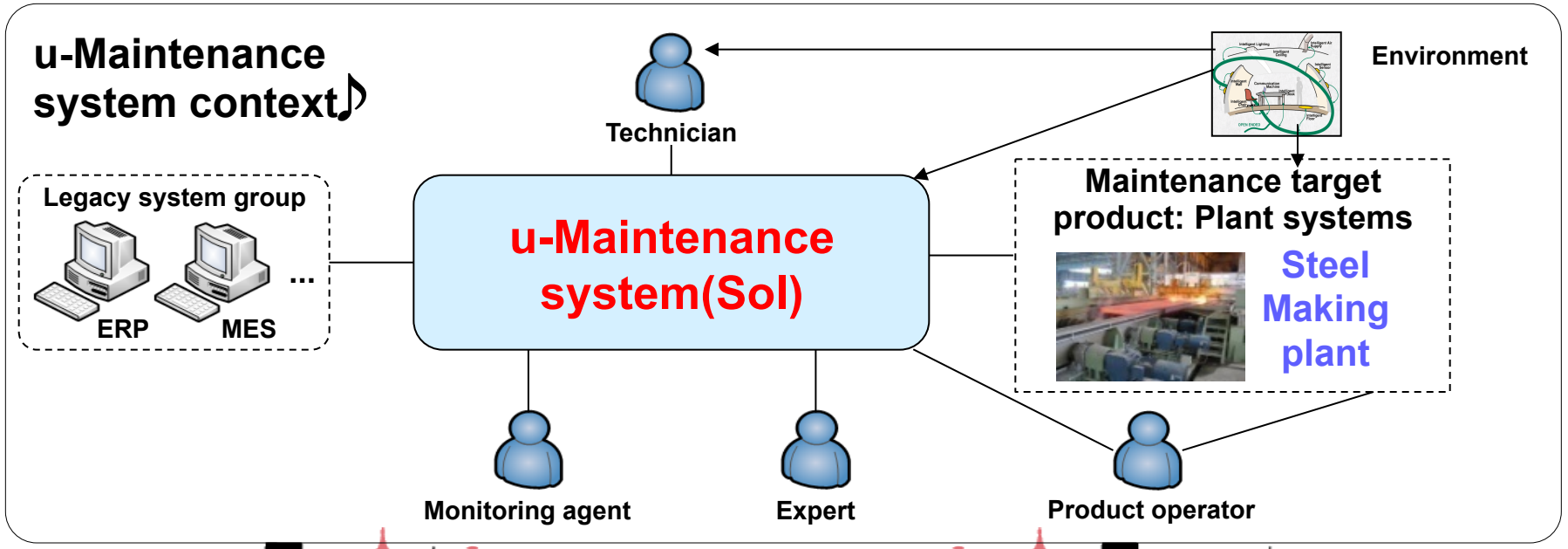
Ubiquitous maintenance (u-Maintenance) system

❑ Maintenance system is [1]

- A system which support maintenance activities to keep physical assets in the desired operating condition or to restore them to this condition.

❑ Ubiquitous maintenance (u-Maintenance) system is

- A system which support the maintenance activities by utilizing ubiquitous tech nologies.



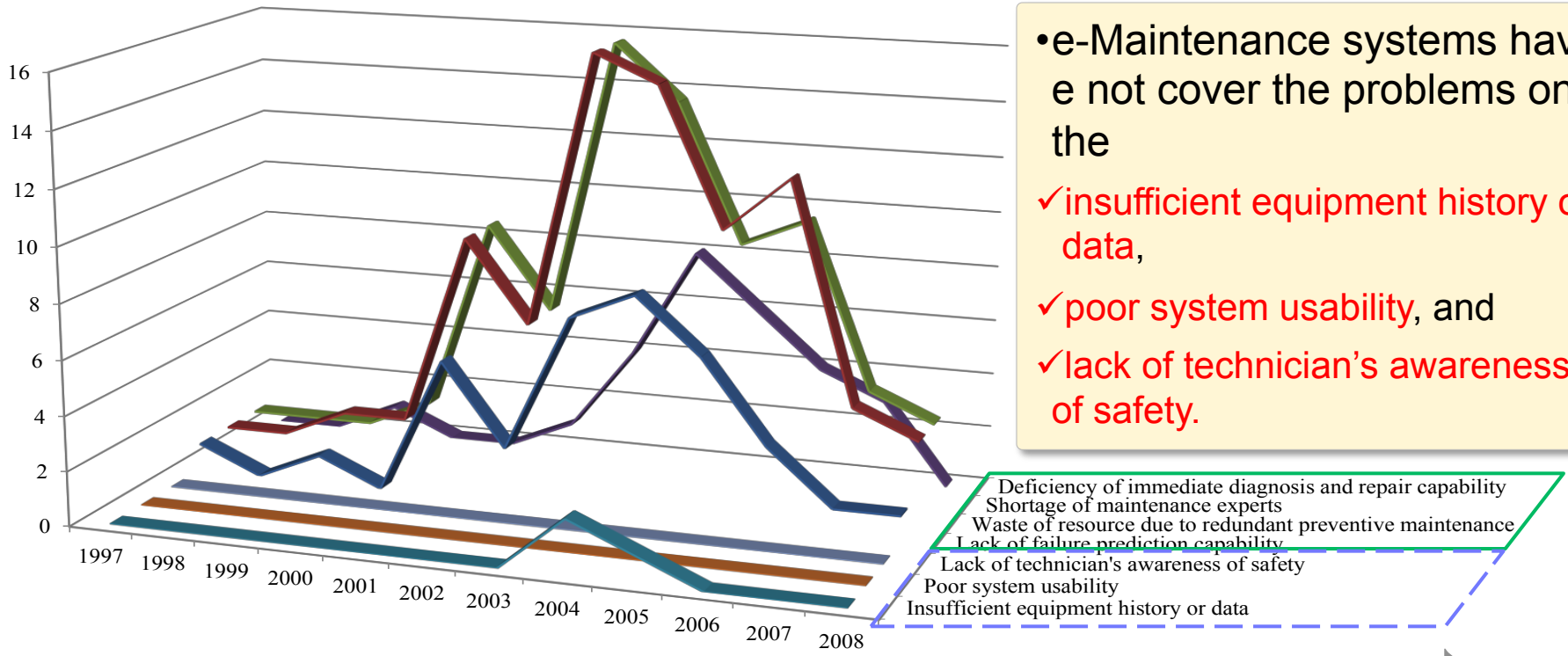
Problems of the existing maintenance systems

- According to literature and field surveys, the existing maintenance systems have the following problems.

- ❑ **Lack of failure prediction capability** (from [1])
- ❑ **Waste of resource due to redundant preventive maintenance** (from [1])
- ❑ **Shortage of maintenance experts** (from [2] and field survey)
- ❑ **Deficiency of immediate diagnosis and repair capability for broken equipment** (from [3] and field survey)
- ❑ **Insufficient equipment history or data** (from [4] and field survey)
- ❑ **Poor system usability** (from field survey)
- ❑ **Lack of technician's awareness of safety** (from field survey)
- ❑ **Etc.**

Limitation of existing researches on maintenance systems

- **The existing researches on maintenance systems solved partly.**
  - e.g. e-Maintenance systems have been researched by utilizing e-technologies (web, wireless com munications, and mobile devices, etc.) to solve the problems in the green box. [5].



Annual number of e-Maintenance system literature on the existing problems of maintenance systems

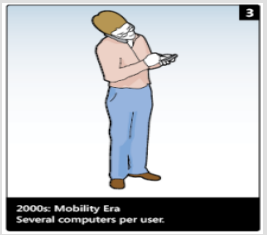
- e-Maintenance systems hav e not cover the problems on the
  - ✓insufficient equipment history or data,
  - ✓poor system usability, and
  - ✓lack of technician's awareness of safety.

A new maintenance system should be studied to address the whole problems.

Potential of ubiquitous technology and Necessity of u-Maintenance system

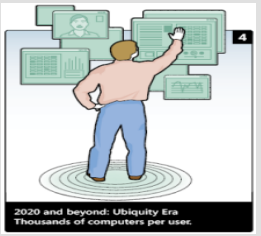
e-Technology

- Feature: Several computers per one user
- Typically uses:
  - Web
  - Wireless communication
  - Mobile devices



Ubiquitous technology

- Feature: Thousands computers per one user
- Typically uses:
  - Context-awareness
  - Wireless sensor network
  - Natural user interface



- **The pervasive computing and communication capabilities of ubiquitous technology have the potential to solve the uncovered problems :**
  - Capability to **acquire/exchange/utilize extensive information** on things

  ➔ can be applied to solve the problem on "**insufficient equipment history or data**".
  - Capability to **perceive a situation autonomously and support maintenance activities** in the most suitable way to the situation

  ➔ can be applied to solve the problems on "**poor system usability**" and "**lack of technician's awareness of safety**".

Existing researches related to u-Maintenance system

Research (Year)	Problems of the existing maintenance systems				Deliverables
	Insufficient equipment history or data	Poor system usability	Lack of technician's awareness of safety	...	
ARVIKA & ARTESAS (1999 ~ 2006)	X	O	O	...	Technician support system using augmented reality
PROMISE (2004 ~ 2008)	O	X	O	...	Maintenance system using smart embedded device
DYNAMITE (2005 ~ 2009)	O	X	X	...	e-Maintenance system using ubiquitous technology
ARMAR (2005 ~ Present)	X	O	O	...	Technician support system using augmented reality
SmartFactoryKL (2005 ~ Present)	X	O	X	...	Technician support system using ubiquitous technology
...	...	...	...	...	...

The existing researches have been focused on the development of a particular technology and its laboratory prototype, but not on systematic design methodology.

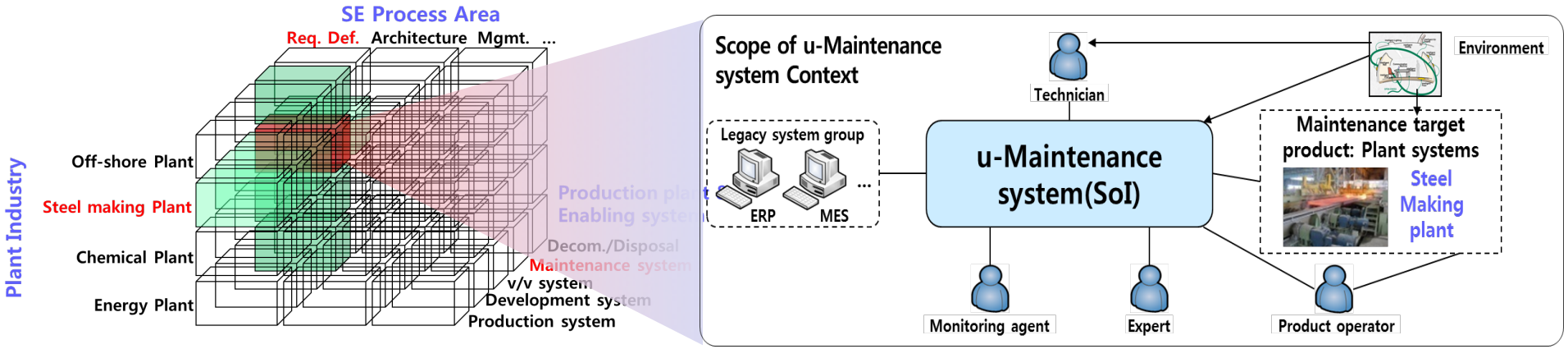
For example, in the domain of ubiquitous systems :

- **The literatures often report that a system, working completely in a laboratory environment, operates against a user's intent in a real environment. [25]**
- **The literatures point out the immature development methods and tools as the cause of the problem. [26]**

A detail methodology, facilitating the systems engineering process for the u-Maintenance systems, should be developed.

Objectives

- To develop the requirements development methodology (process, methods and tools) for u-Maintenance system of production plant system.
- To demonstrate the case study of the u-Maintenance system of a steel making plant for validation.



2. Requirements development met hod(ways and means) for ubiquito us maintenance system

Requirements development process tailoring considerations

- **The standard(ISO/IEC 15288) requirements development processes are tailored, by considering two distinguishing factors, to suit u-Maintenance system especially.**

❑ **[F#1] Dynamic adaptation to new situations:**

- This factor support the maintenance activities in the most suitable way to situations.
- The u-Maintenance system adapts its behavior dynamically to new situations.

➔ In order to consider this factor, the methodology should identify the anticipated situations to which the u-Maintenance system would adapt.

❑ **[F#2] Bidirectional interaction between a maintenance system and a maintenance target product (e.g. steel making plant):**

- The u-Maintenance system and its target product operate at the same time while interacting with each other.

➔ In order to reflect such bidirectional interaction, the methodology should consider the both of maintenance activities and product operating activities

Requirements development process tailoring

- **Drive tasks to perform requirements definition process**

Consideration factors

[F#1] Dynamic adaptation to new situations (Identification of the anticipated situations)

[F#2] Bidirectional interaction between a maintenance system and a product (Consideration on the maintenance and product operating activities)

Requirement definition process complemental tasks

Derived tasks

A.1.1. Field survey

A.1.2. Selection of target maintenance activity

A.1.3. Selection of target product operating activity

A.1.4. Modeling of existing maintenance and product operating activities (As-Is)

A.1.5. Modeling of u-Maintenance activity (To-Be)

A.1.6. Gap analysis and User requirements derivation

A.1.7. Evaluation of user requirements

A.1.8. Selection of target user requirements

Processes of the requirements development methodology

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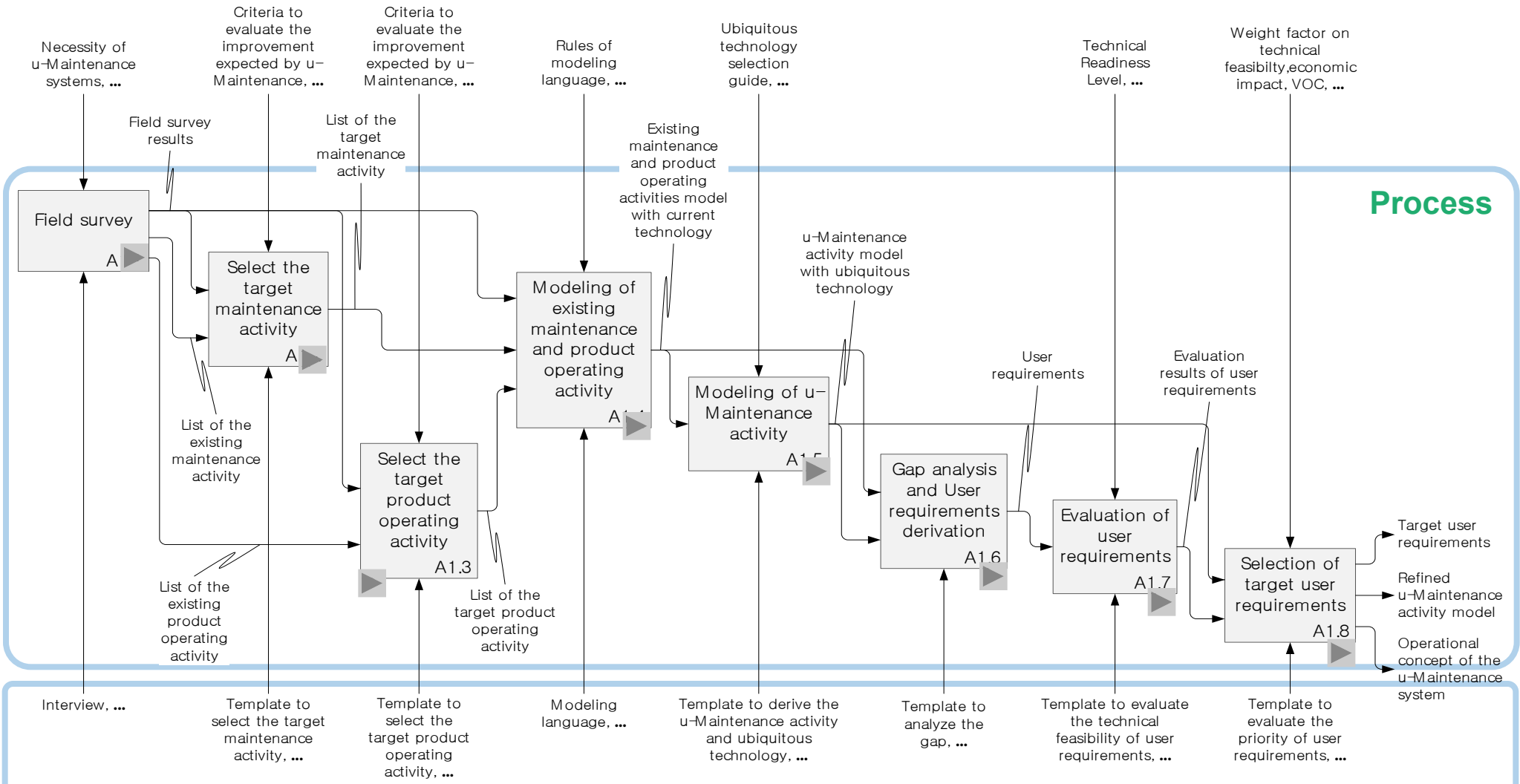
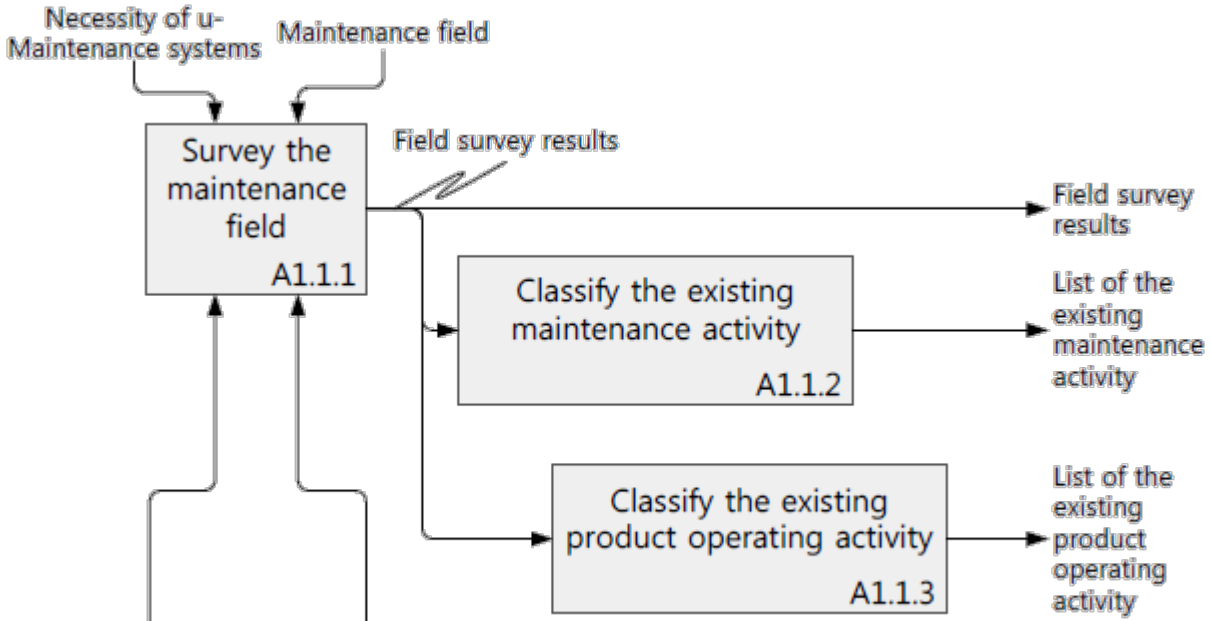


A1.1 Field survey

- **Process to understand the existing maintenance and product operating activities in the maintenance field**

Ways

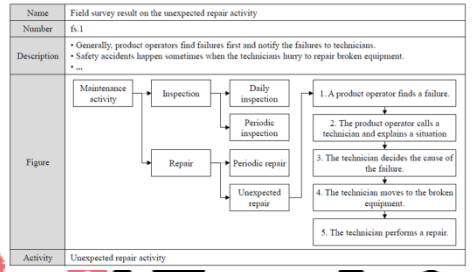


Means

Interview

Workshop

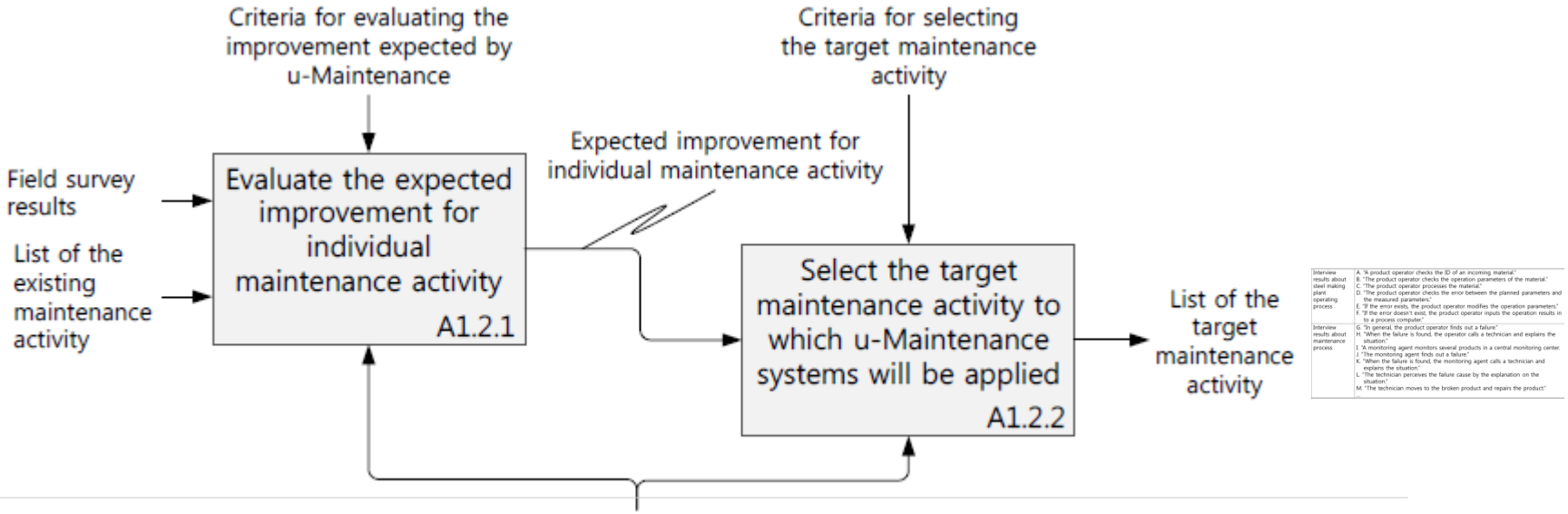
Template♪ for field survey♪



A1.2 Selection of target maintenance activity

- Process to select the target maintenance activity, to which u-Maintenance systems will be applied, among the list of the existing maintenance activity
  - Why? The development project of a u-Maintenance system would be driven with small manpower and budget.
  - Why? It is necessary to focus the development efforts on few existing maintenance activities for which large improvements are expected.

Ways



Means

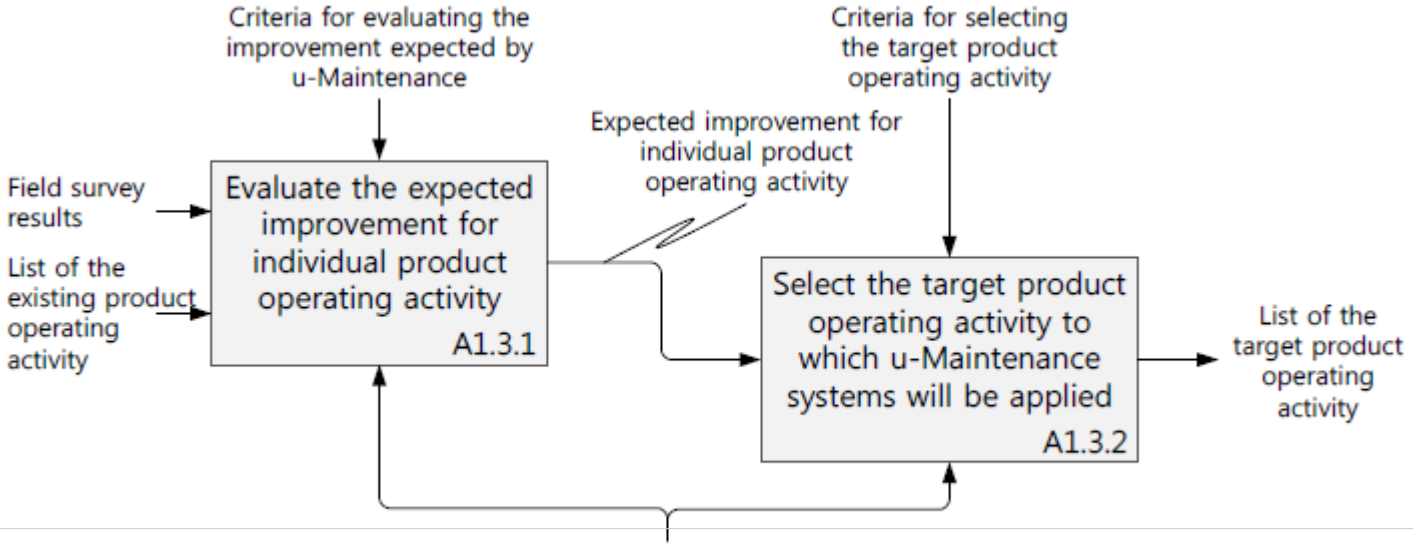
Template to select the target maintenance activity

Existing maintenance activites		Characteristics of existing maintenance activity			Improvement
		A. Complexity of task (1-10 scale)	B. Number of occurrences (1-10 scale)	C. Loss for individual occurrence (1-10 scale)	A + B × C
Inspection	Daily inspection	5	10	1	15
	Periodic inspection	5	8	1	13
Repair	Periodic repair	8	3	3	17
	Unexpected repair	10	1	10	20

A1.3 Selection of target product operating activity

- Process to select **the target product operating activity, to which u-Maintenance systems will be applied**, among the list of the existing product operating activity

Ways



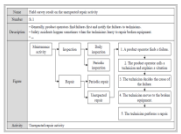
Means

Existing maintenance activites		Characteristics of existing maintenance activity			Improvement
		A. Complexity of task (1-10 scale)	B. Number of occurrences (1-10 scale)	C. Loss for individual occurrence (1-10 scale)	A + B × C
Inspection	Daily inspection	5	10	1	15
	Periodic inspection	5	8	1	13
Repair	Periodic repair	8	3	3	17
	Unexpected repair	10	1	10	20

A1.4 Modeling of existing maintenance and product operating activities

- **Process to model the target maintenance and product operating activities**
  - Why? The developers are likely to understand the activities abstractly since they concentrate on the ubiquitous technology.
  - Why? Therefore, the modeling process is required to make the developers understand the existing activities in detail.

Ways



Field survey results

List of the target maintenance activity

List of the target product operating activity

Rules of modeling language

Criteria to verify the existing maintenance and product operating activities model

Existing maintenance and product operating activities model

Model the existing maintenance and product operating activities
A1.4.1

Verify the existing maintenance and product operating activities model
A1.4.2

Model the existing maintenance and product operating activities with current technology
A1.4.3

Existing maintenance and product operating activities model with current technology

Means

Modeling language

Activity Model
EFFBD, etc.

Computer aided systems engineering tool

CORE 8.0

Template to model the existing maintenance and product operating activities

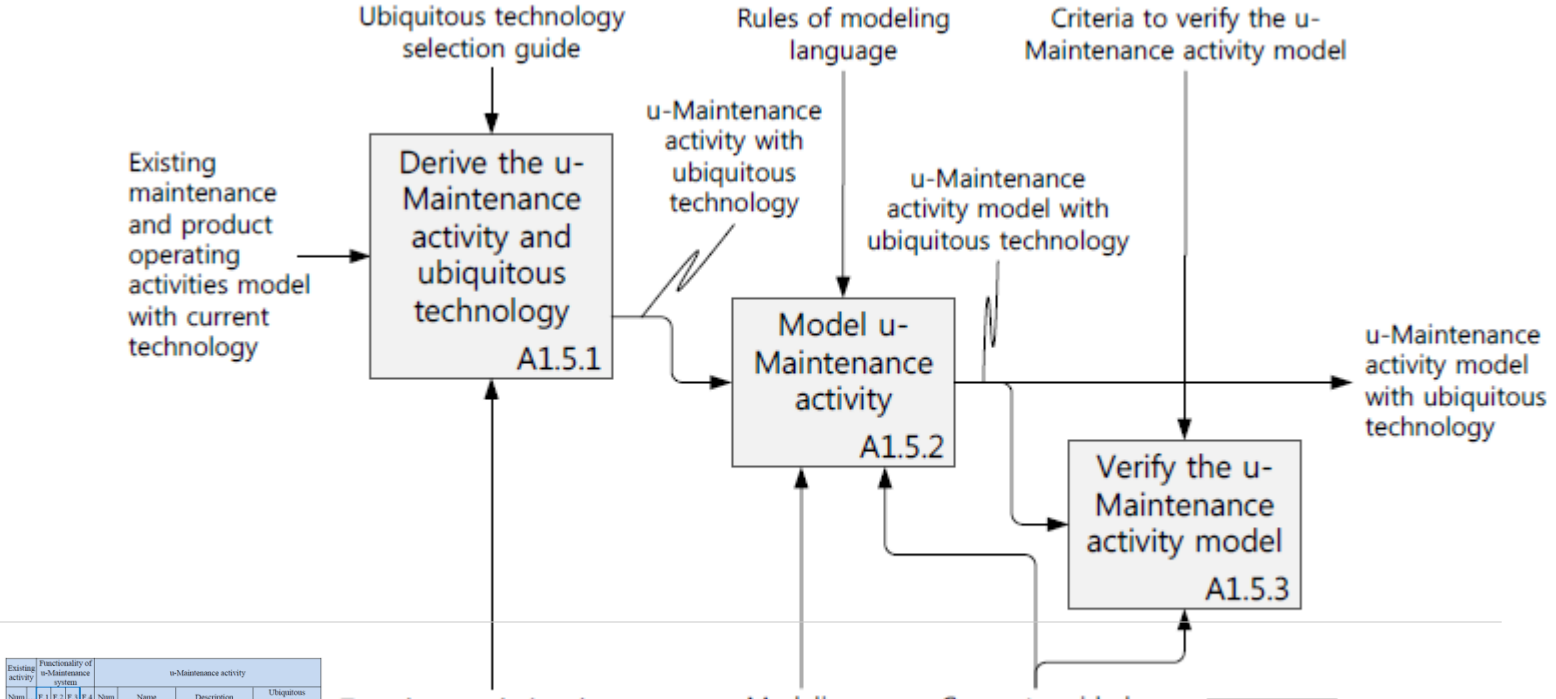
Gap			User requirement										
Num	Name	Description	Num	Name	Who	Auxiliary verb	Verb	What (I)	How (Technology)	How much	Why	When	Where
g.2	Gap about the support	• The system finds a failure automatically.	ur.3	Automatic detection of a failure in a product operating room	Product operator	shall	receive	the failure warning, detected by the system	via context-awareness	within 5 seconds	-	after a failure is detected	in a product operating room

A1.5 Modeling of u-Maintenance activity

- **Process to model the u-Maintenance activity, which improves the existing maintenance activity**
  - Current the u-Maintenance activity is derived unsystematically by the developers' technological knowledge and experience.
  - There is high probability that the derived u-Maintenance activity is biased for a particular ubiquitous technology familiar with the developers.

Ways

Means



A1.6 Gap analysis and User requirements derivation

- This process

1)analyze the gap between the existing maintenance and product operating activit ies model and the u-Maintenance activity model and

2)derive the user requirements of the u-Maintenance system from the gap.

Ways

u-Maintenance activity model with ubiquitous technology

Existing maintenance and product operating activities model with current technology

Group the u-Maintenance activity A1.6.1

u-Maintenance activity group

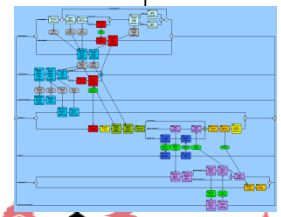
Analyse the gap between the existing maintenance activity and the u-Maintenance activity A1.6.2

Gap between the existing maintenance activity and the u-Maintenance activity

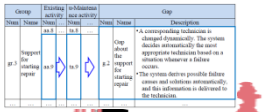
Derive the user requirements A1.6.3

User requirements

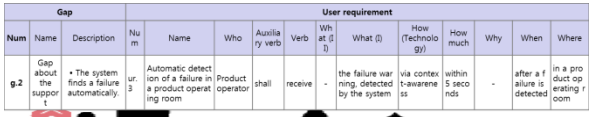
Means



Template to analyze the gap



Template to derive the user requirement

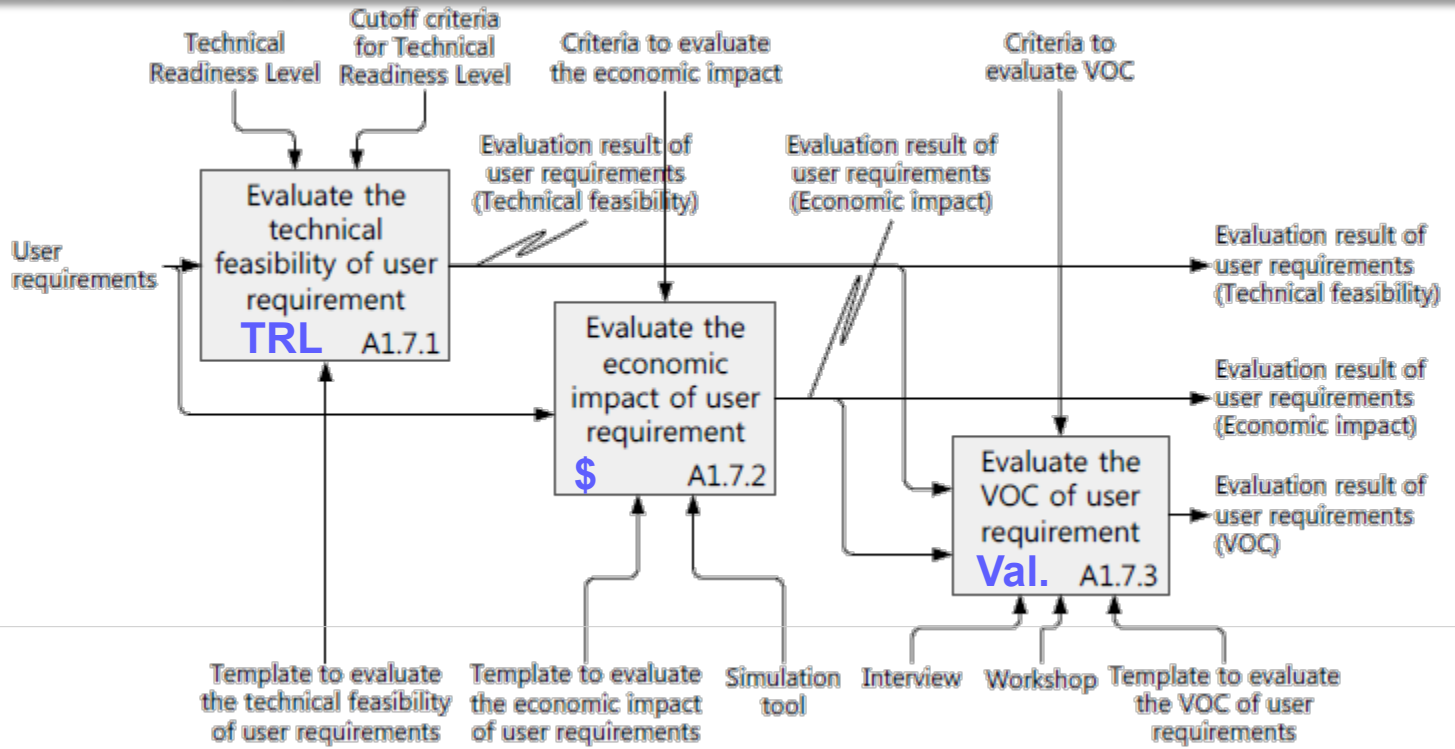


Gap			User requirement										
Num	Name	Description	Num	Name	Who	Auxiliary verb	Verb	What (I)	How (Technology)	How much	Why	When	Where
g.2	Gap about the support	• The system finds a failure automatically.	ur. 3	Automatic detection of a failure in a product operating room	Product operator	shall	receive	the failure warning, detected by the system	via context-awareness	within 5 seconds	-	after a failure is detected	in a product operating room

A1.7 Evaluation of user requirements

- **Process to evaluate the individual user requirements in the perspectives of technical feasibility, economic impact, and VOC (Voice-of-Customer)**
  - Why? At present, the user requirements of u-Maintenance systems are evaluated by the developers' technical knowledge and experience.
  - Why? A systematic process is required to evaluate the user requirements quantitatively in various aspects.

Ways



Means

User requirement	Technical Readiness Level (TRL) of Ubiquitous technology				Cutoff criteria (0)	Technical feasibility
No.	Wireless sensor network	Context-awareness	Real-time locating system	Smart phone		
ur.1	7	-	-	-	O	7
ur.2	-	4	-	-	O	4

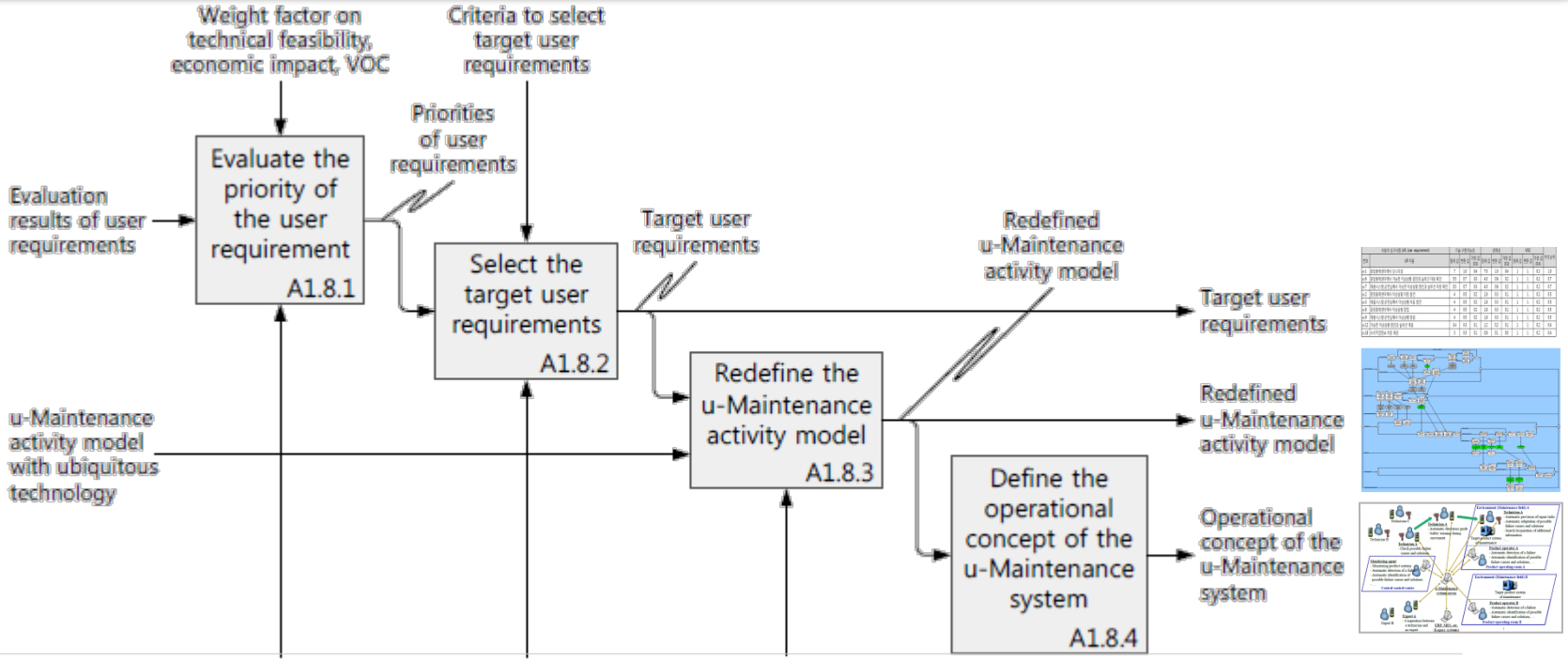
User requirement		Criterion #1 (Time consumption)				…	Economic impact (%)
Num	Name	UR value (min)	Existing value (min)	Improvement (%)	Weight factor	…	
ur.1	…	132.65	137.6	3.6	1	…	3.6
ur.2	…	132.65	137.6	3.6	1	…	3.6
ur.4	…	129.6	137.6	5.8	1	…	5.8
ur.6	…	129.6	137.6	5.8	1	…	5.8
…	…	…	…	…	…	…	…

User requirement		VOC
Num	Name	
ur.1	Monitoring in a central control center	1
ur.2	Automatic detection of a failure in a central control center	1
ur.4	Automatic decision of a corresponding technician in a central control center	0
ur.5	Automatic decision of a corresponding technician in a product operating room	0
ur.6	Automatic identification of possible failure causes and solutions in a central control center	1
…	…	

A1.8 Selection of target user requirements

- Process to select target user requirements, which will be implemented into a solution, by prioritizing the user requirements based on the previous evaluation results
  - This process enables the developers to identify such important and feasible user requirements objectively.

Ways



Means

Template to evaluate the priority of user requirements

Workshop

Computer aided systems engineering tool

User requirement		Technical feasibility			Economic impact			VOC			Priority
No.	Name	Original value	Converted value	Weight factor (0.4)	Original value	Converted value	Weight factor (0.4)	Original value	Converted value	Weight factor (0.2)	
ur.1	…	7	1.0	0.4	3.6	0.1	0.0	1	1	0.2	0.6
ur.6	…	5.5	0.7	0.3	5.8	0.2	0.1	1	1	0.2	0.6
ur.2	…	4	0.5	0.2	3.6	0.1	0.0	1	1	0.2	0.4
ur.4	…	2	0.1	0.0	5.8	0.2	0.1	0	0	0	0.1
…	…	…	…	…	…	…	…	…	…	…	…

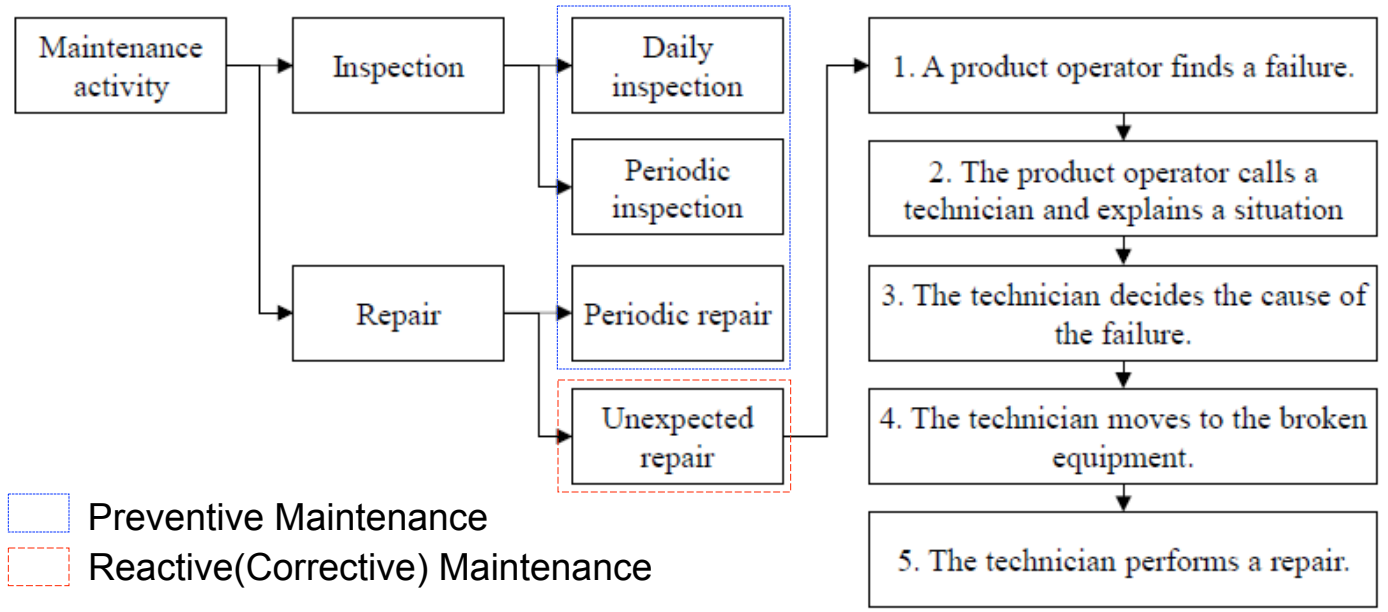
CORE 8.0

3. Case study of the requirements development method for ubiquitous maintenance system

A1.1 Field survey

- The maintenance field of the steel making plant is surveyed via interviews and w orkshops to define the lists of the existing maintenance and product operating a ctivities.

[Example of the field survey re sult on mainten ance]♪

Name	Field survey result on the unexpected repair activity
Number	fs.1
Description	• Generally, product operators find failures first and notify the failures to technicians. • Safety accidents happen sometimes when the technicians hurry to repair broken equipment. • ...
Figure	
Activity	Unexpected repair activity

A1.2 Selection of target maintenance scenarios

- The expected improvement of each maintenance activity is assessed in the light of the complexity of
  - Maintenance activity
  - Occurrence frequency of the maintenance activity
  - Loss due to individual occurrence.

➔ The **unexpected repair activity** is selected as the target maintenance scenario.

Existing maintenance activities		Characteristics of existing maintenance activity			Improvement
		A. Complexity of task (1-10 scale)	B. Number of occurrences (1-10 scale)	C. Loss for individual occurrence (1-10 scale)	A + B × C
Inspection	Daily inspection	5	10	1	15
	Periodic inspection	5	8	1	13
Repair	Periodic repair	8	3	3	17
	Unexpected repair	10	1	10	20

[Selection of the target maintenance activity]♪

Cf. The values are defined by this research team for illustration.

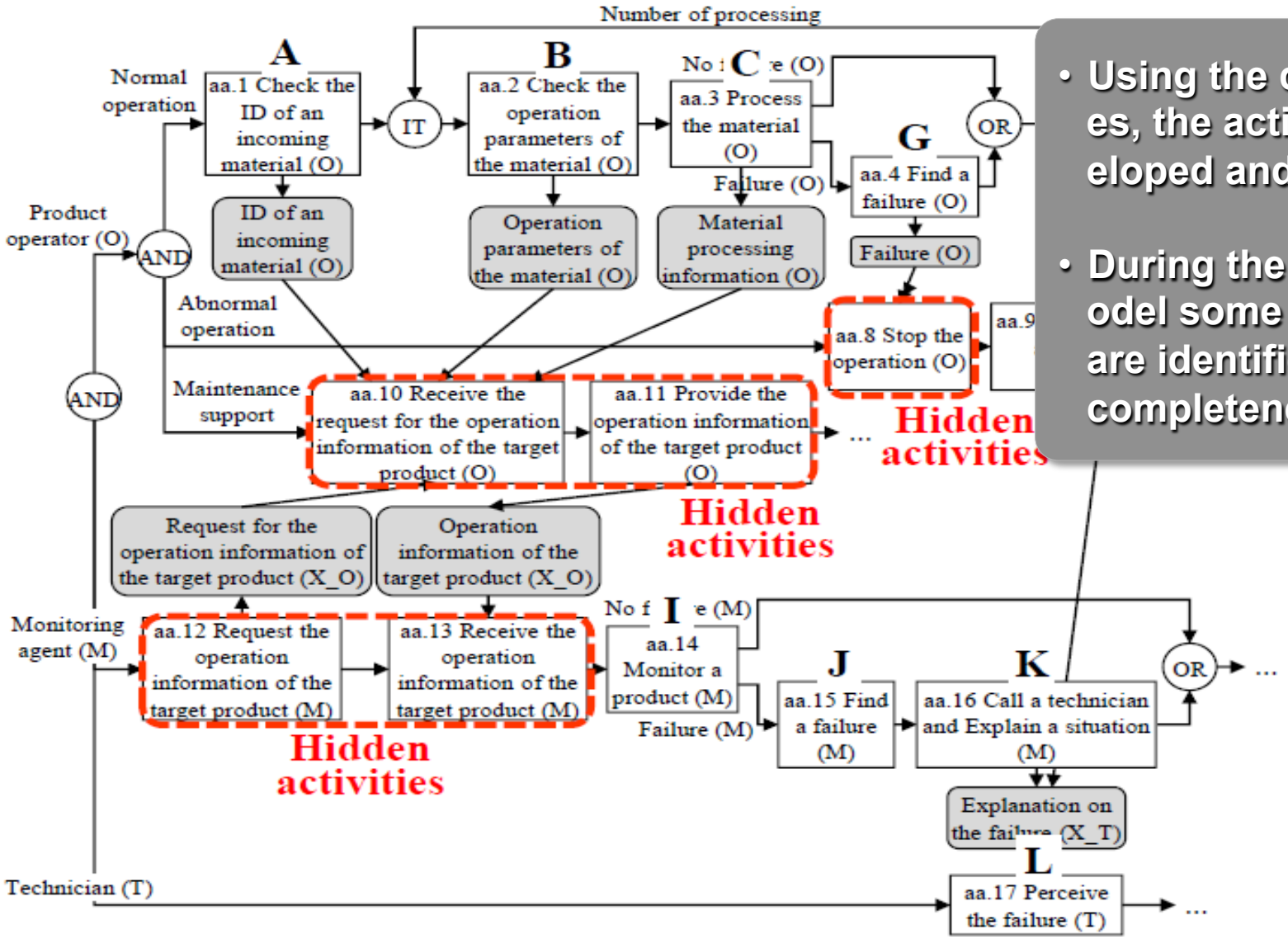
※ The steel rolling process is considered for the unexpected repair because of the importance of the process.

A1.4 Modeling of existing maintenance and plant operating activity

- **From the interview, the scenarios of operating and maintenance processes for st eel making plant are developed.**

Interview results about steel making **plant operating process**	A. "A product operator checks the ID of an incoming material." B. "The product operator checks the operation parameters of the material." C. "The product operator processes the material." D. "The product operator checks the error between the planned parameters and the measured parameters." E. "If the error exists, the product operator modifies the operation parameters." F. "If the error doesn't exist, the product operator inputs the operation results into a process computer."
Interview results about **maintenance process**	G. "In general, the product operator finds out a failure." H. "When the failure is found, the operator calls a technician and explains the situation." I. "A monitoring agent monitors several products in a central monitoring center. J. "The monitoring agent finds out a failure." K. "When the failure is found, the monitoring agent calls a technician and explains the situation." L. "The technician perceives the failure cause by the explanation on the situation." M. "The technician moves to the broken product and repairs the product." …

A1.4 Modeling of existing maintenance and plant operating activity



- Using the developed activities, the activity model is developed and analyzed.
- During the analysis of the model some hidden activities are identified and enhanced completeness.

[Example of the existing maintenance and product operating activities model]

A1.5 Modeling of u-Maintenance activity

- **The u-Maintenance activities and relevant ubiquitous technologies are derived by incorporating the desirable functionalities of the u-Maintenance system into the existing maintenance and product operating activities [28].**

F.1 Support for the mobility of technicians
F.2 Acquisition of extensive information on things
F.3 Automatic context-awareness of the system
F.4 Prevention of the safety accidents of the technicians

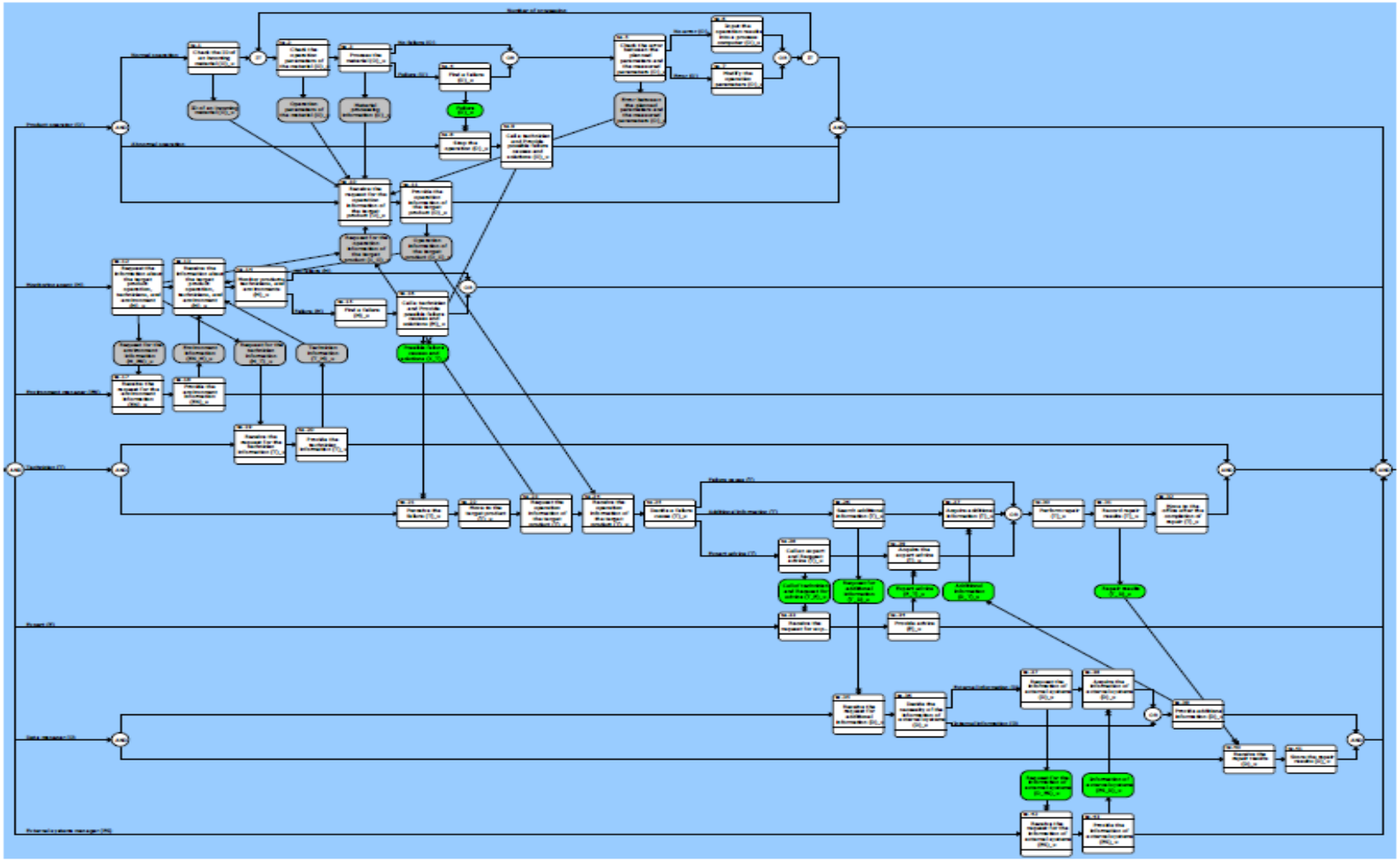
Num	Name	Description	Current technology	Stakeholder
aa.9	Call a technician and Explain a situation (O)	The product operator calls a technician and explains a situation.	Phone	Product operator (O)

Existing activity		Functionality of u-Maintenance system				u-Maintenance activity			
Num	…	F.1	F.2	F.3	F.4	Num	Name	Description	Ubiquitous technology
aa.8	…	X		X	X	ta.8	Stop the operation (O)_u	The product operator stops the operation.	PLC
aa.9		O	O	O		ta.9	Call a technician and Provide possible failure causes and solutions (O)_u	The u-Maintenance system automatically decides the most appropriate technician, possible failure causes, and solutions.	Context-awareness, Wireless sensor networks, Real-time locating system, Smart phone

[Example of deriving the u-Maintenance activities]♪

A1.5 Modeling of u-Maintenance activity

- The u-Maintenance model is developed using u-Maintenance activity



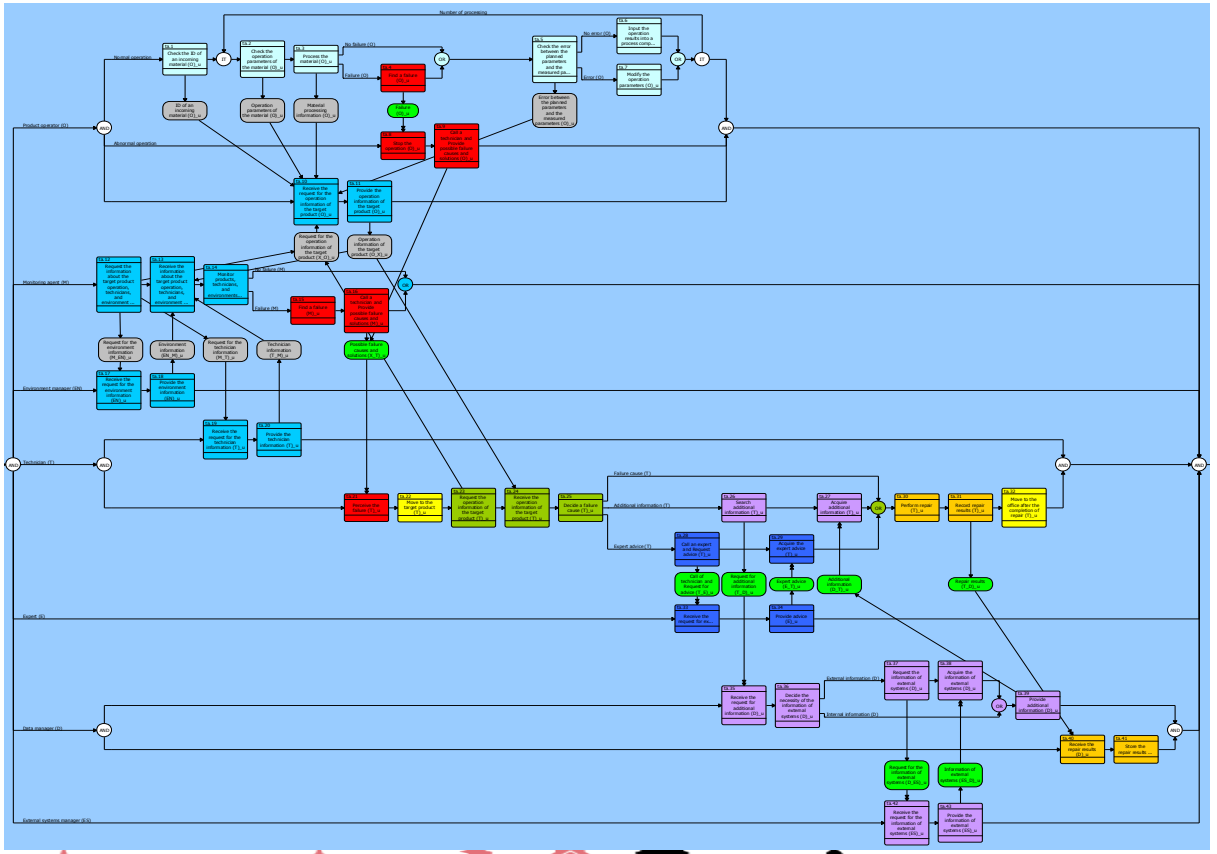
[u-Maintenance activity model]

A1.6 Gap analysis and User requirements derivation

- To analyze the developed u-Maintenance model, the similar activities are groupe d together as capability because the similar activities can be repetitively appeare d in the models for the logical completeness of the models
- Eight capability groups are derived from the u-Maintenance activities

Capability groups ♪

- gr.1 Product operation
- gr.2 Product monitoring
- gr.3 Support for starting repair
- gr.4 Support for movement
- gr.5 Support for deciding a failure c ause
- gr.6 Support for the cooperation wit h an expert
- gr.7 Support for searching addition al information
- gr.8 Support for performing repair



A1.6 Gap analysis and User requirements derivation

- After grouping the activities, the gap between the existing maintenance activities and the u-Maintenance activities are analyzed and identified from capability viewpoints.

Group		Existing activity		u-Maintenance activity		Gap		
Num	Name	Num	…	Num	…	Num	Name	Description
gr.3	Support for starting repair	aa.8	…	ta.8	…	g.2	Gap about the support for starting repair	• A corresponding technician is changed dynamically. The system decides automatically the most appropriate technician based on a situation whenever a failure occurs. • The system derives possible failure causes and solutions automatically, and this information is delivered to the technician.
		aa.9		ta.9				
…	…	…	…	…	…	…	…	…

A1.6 Gap analysis and User requirements derivation

- Based on the gap analysis results, the user requirements for u-Maintenance system are derived with a formalized requirements description template [29].

Gap		User requirement											
Num	…	Num	Name	A	B	C	D	E	F	G	H	I	J
g.2		ur.4	Automatic decision of a corresponding technician in a central control room	Monitoring agent	shall	receive	…	the information on the most appropriate technician, decided by the system	…	…	…	…	…
		ur.6	Automatic identification of possible failure causes and solutions in a central control room	Monitoring agent	shall	receive	…	the possible failure causes and solutions, derived by the system	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…

A: Who, B: Auxiliary verb, C: Verb, D: What (II), E: What (I), F: How, G: How much, H: Why, I: When, J: Where

[Example of user requirements derivation]

A1.6 Gap analysis and User requirements derivation

- The **derived user requirements** for u-Maintenance system

No.	Name
ur.1	Monitoring in a central control center
ur.2	Automatic detection of a failure in a central control center
ur.3	Automatic detection of a failure in a product operating room
ur.4	Automatic decision of a corresponding technician in a central control center
ur.5	Automatic decision of a corresponding technician in a product operating room
ur.6	Automatic identification of possible failure causes and solutions in a central control center
ur.7	Automatic identification of possible failure causes and solutions in a product operating room
ur.8	Failure notification from a central control center
ur.9	Failure notification from a product operating room
ur.10	Automatic directions guide
ur.11	Safety warning during movement
ur.12	Provision of possible failure causes and solutions
ur.13	Automatic adaptation of possible failure causes and solutions
ur.14	Automatic decision of a corresponding expert
ur.15	Ask the advice of an expert
ur.16	Cooperation between a technician and an expert
ur.17	Search of additional information
ur.18	Automatic provision of repair tasks
ur.19	Safety warning during repair
ur.20	Automatic storage of repair results

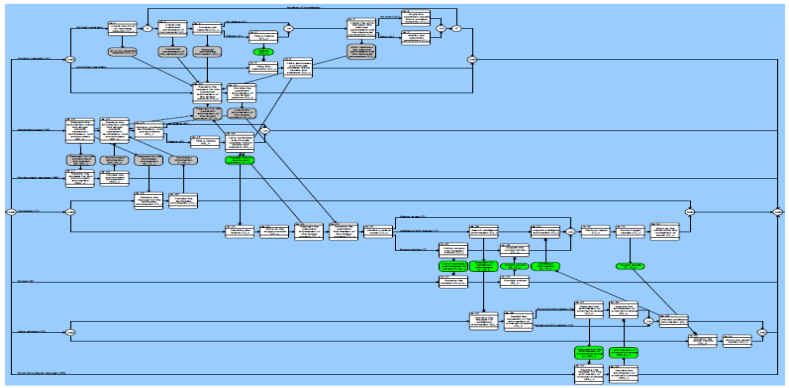
A1.7 Evaluation of user requirements

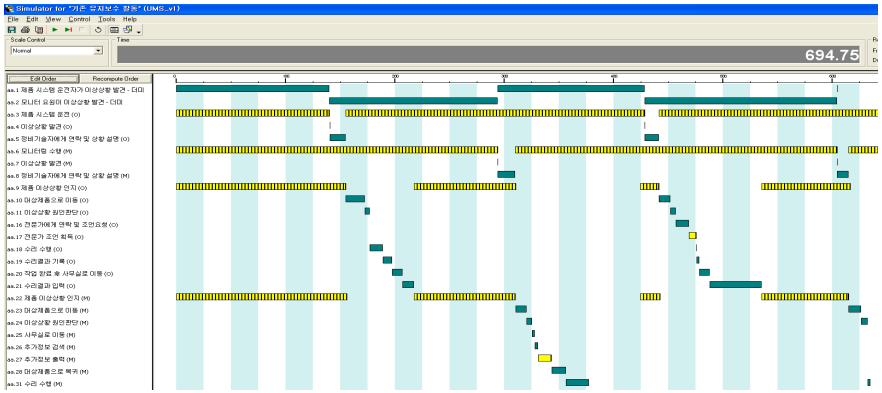
- The technical feasibility of the user requirements is evaluated by employing Technical Readiness Level (TRL) [30].

User requirement	Technical Readiness Level (TRL) of Ubiquitous technology				Cutoff criteria (0)	Technical feasibility
No.	Wireless sensor network	Context-awareness	Real-time locating system	Smart phone		
ur.1	7	-	-	-	O	7
ur.2	-	4	-	-	O	4
ur.3	-	4	-	-	O	4
ur.4	-	2	2	-	O	2
ur.5	-	2	2	-	O	2
ur.6	7	4	-	-	O	5.5
ur.7	7	4	-	-	O	5.5
…						

A1.7 Evaluation of user requirements

- The **economic impact** is evaluated by comparing the **time-line analysis results** of the existing activity model and the u-Maintenance activity model.





Consumed time to achieve the ur1.

User requirement		Criterion #1 (Time consumption)				…	Economic impact (%)
Num	Name	UR value (min)	Existing value (min)	Improvement (%)	Weight factor	…	
ur.1	…	132.65	137.6	3.6	1	…	3.6
ur.2	…	132.65	137.6	3.6	1	…	3.6
ur.4	…	129.6	137.6	5.8	1	…	5.8
ur.6	…	129.6	137.6	5.8	1	…	5.8
…	…	…	…	…	…	…	…

[Example of the economic impact of the user requirements]♪

A1.7 Evaluation of user requirements (User validation)

- **The developed user requirements are validated by the interview and workshop with the maintenance field people.**

Interview results
• "It's very good to show inspection list which is suitable to inspection context. That will upgrade the legacy system." • "Steel mill will be built in oversea, and a central center will monitor and control the overseas steel mill. For this reason, the capabilities of remote monitoring and automatic status notification are necessary." • "GE monitors aircraft engines around the world. GE predicts the failures of the engines and notifies the replacement time. StatoilHydro has the same system for an oil prospecting ship likewise." • "Sensors are already attached to major equipment, but they are not attached to peripheral equipment. Wireless sensors have the problems of battery and increasing maintenance spots. However, the pressure and temperature sensors which transmit data every 1~2 minute are applicable to a field because their battery life is few years." • …

User requirement		Val. Results	Rationale
Num	Name		
ur.1	Monitoring in a central control center	1	Link
ur.2	Automatic detection of a failure in a central control center	1	Link
ur.4	Automatic decision of a corresponding technician in a central control center	0	Link
ur.5	Automatic decision of a corresponding technician in a product operating room	0	Link
ur.6	Automatic identification of possible failure causes and solutions in a central control center	1	Link
…	…		

A1.8 Selection of target user requirements

- The target user requirements, which will be implemented into a solution, are selected by prioritizing the user requirements based on the previous evaluation results.
- In this research, all of the alternative requirements are selected to show the concept of u-Maintenance system fully.

User requirement		Technical feasibility			Economic impact			VOC			Priority
No.	Name	Original value	Converted value	Weight factor (0.4)	Original value	Converted value	Weight factor (0.4)	Original value	Converted value	Weight factor (0.2)	
ur.1	…	7	1.0	0.4	3.6	0.1	0.0	1	1	0.2	0.6
ur.6	…	5.5	0.7	0.3	5.8	0.2	0.1	1	1	0.2	0.6
ur.2	…	4	0.5	0.2	3.6	0.1	0.0	1	1	0.2	0.4
ur.4	…	2	0.1	0.0	5.8	0.2	0.1	0	0	0	0.1
…	…	…	…	…	…	…	…	…	…	…	…

[Example of selecting the target user requirements]♪

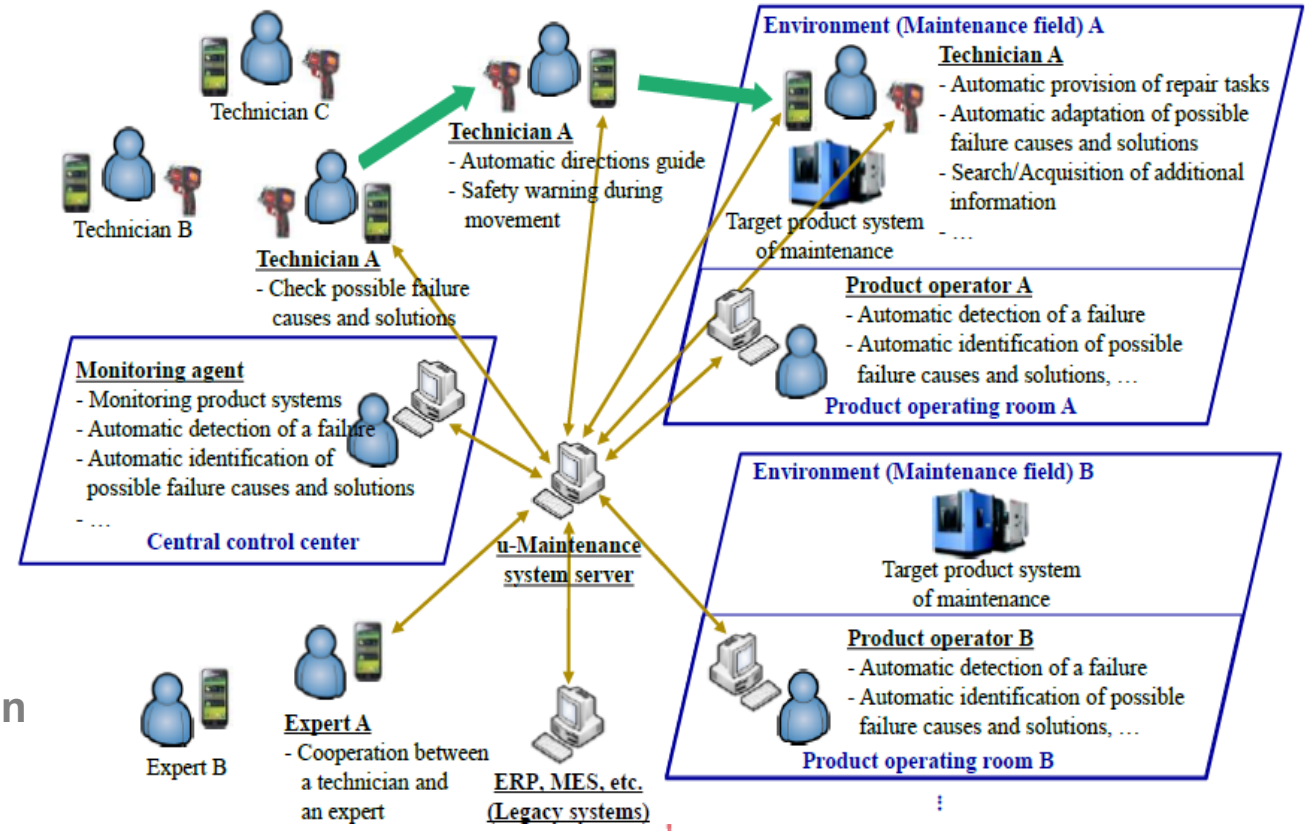
A1.8 Selection of target user requirements

- The **u-Maintenance system activity model** is refined to reflect the target user requirements.
- Then, the **Concept of Operations** of the u-Maintenance system is defined based on the refined activity model.

URs ♪

No.	Name	Priority
ur.1	Monitoring in a central control center	0.6
ur.2	Automatic detection of a failure in a central control center	0.4
ur.3	Automatic detection of a failure in a product operating room	0.4
ur.6	Automatic identification of possible failure causes and solutions in a central control center	0.6
ur.7	Automatic identification of possible failure causes and solutions in a product operating room	0.6
ur.8	Failure notification from a central control center	0.5
…	…	

Baselined Concept of Operations of the u-Maintenance system♪

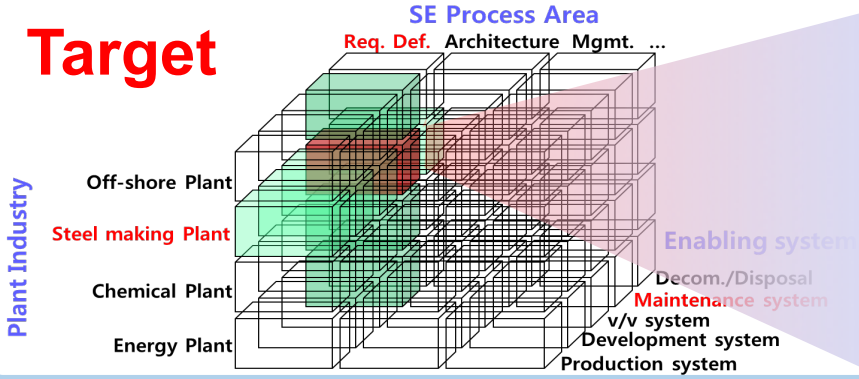


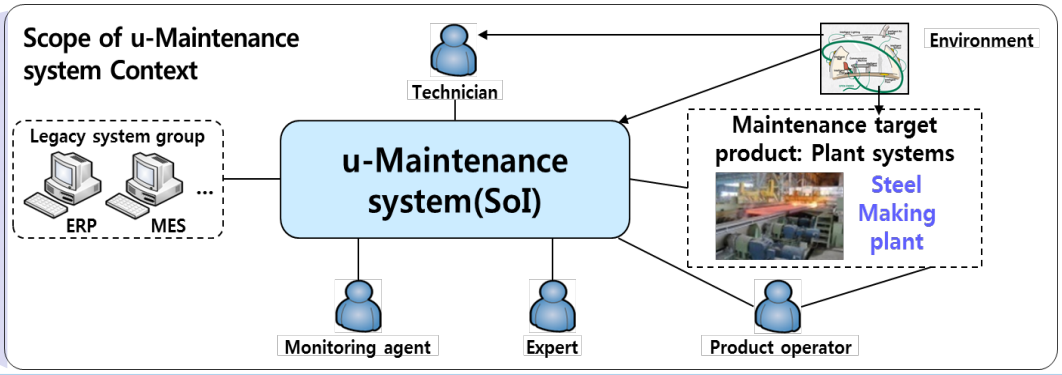
5. Conclusion

Conclusion

- The requirements development methodology of u-Maintenance system is proposed for steel-making plant domain.

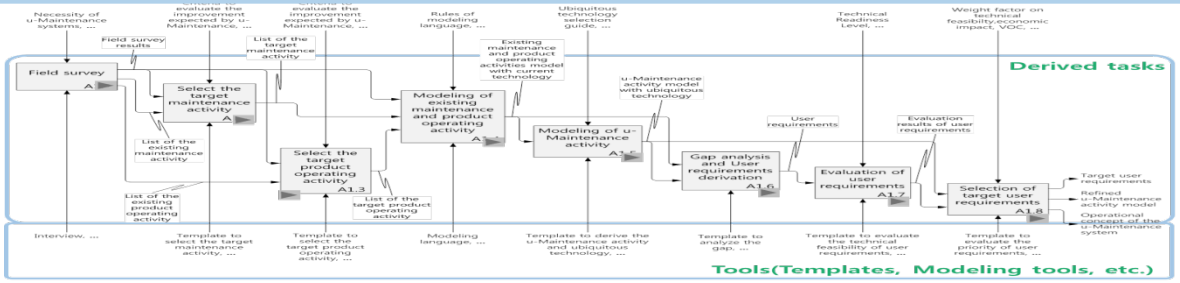
Target





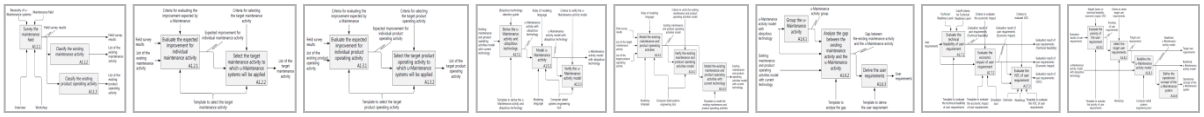
Process

Requirements definition process tailored to u-Maintenance system for plant system.



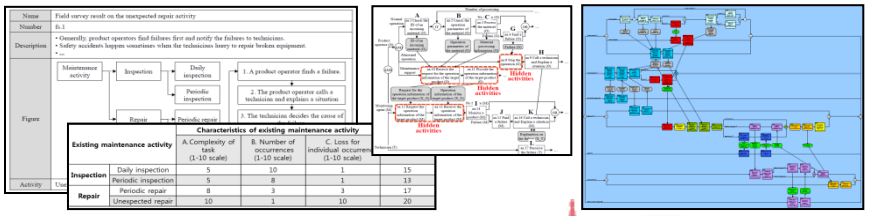
Methods

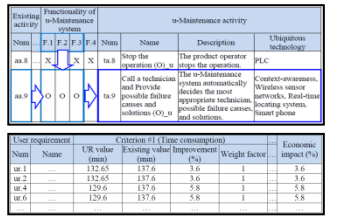
Tool using methods (ways) (Procedures, Rules, criteria, etc.)



Tools

Models, Templates





Lessons learned

- **The proposed requirements development methodology was effectively used to develop and validate ubiquitous mainte nance system requirements of production plant.**
- **Through analysis of operational model, we can assure that t he pervasive computing and communication capabilities of ubiquitous technology have the potential to solve the unco vered problems of maintenance system of production plant.**
  - Capability to **acquire/exchange/utilize extensive information** on things

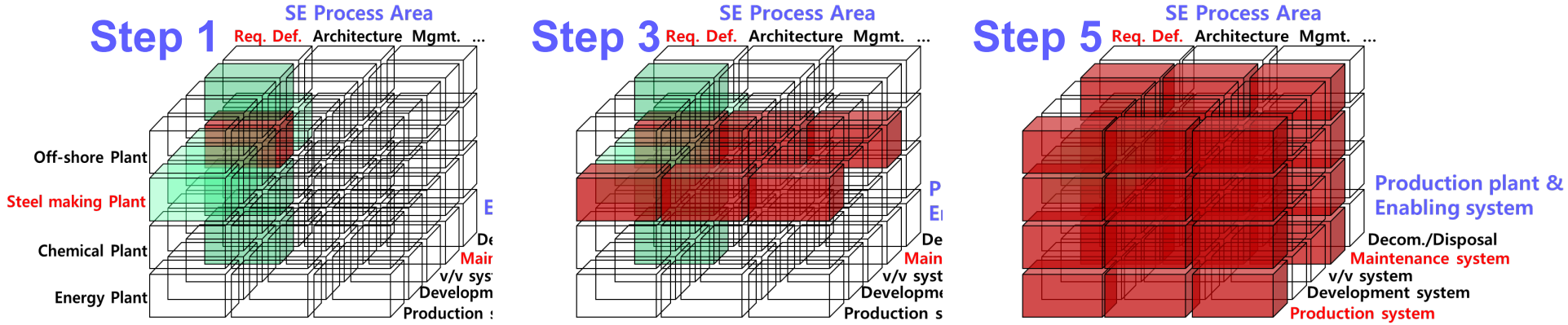
➔ can be applied to solve the problem on "insufficient equipment histo ry or data".

  - Capability to **perceive a situation autonomously and support maintenanc e activities** in the most suitable way to the situation

➔ can be applied to solve the problems on "poor system usability" and "lack of technician's awareness of safety".

Future research needed

- Step 1: Steel-making plant / Maintenance system / Req. Def.
- Step 2: Steel-making plant / Maintenance system / Sol. Def.
- Step 3: Steel-making plant / Production plant / All SE process area
- Step 4: Off-shore plant / Production plant & Maintenance system
- Step 5: Other plant / Production plant & Maintenance system



Q & A

Thank you

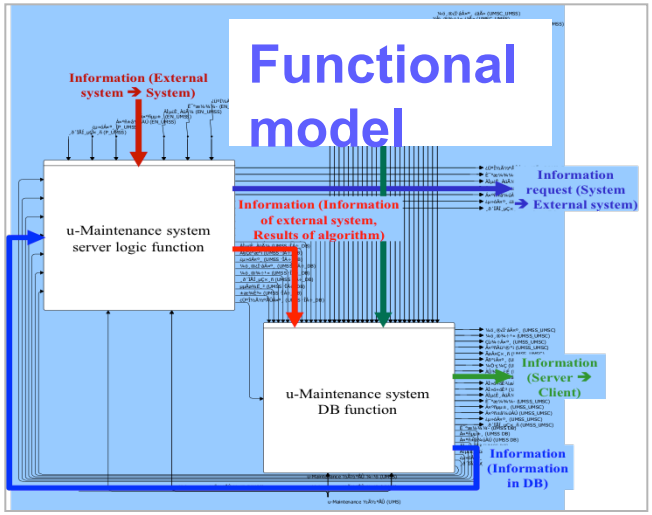
Survey

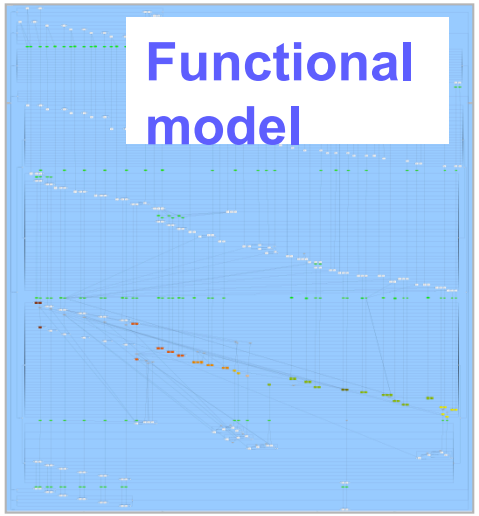
Please take the time to rate this presentation by submitting the web survey found at:

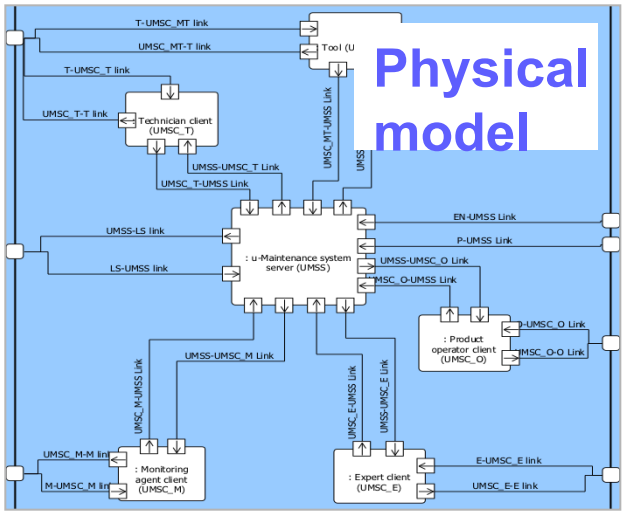
www.incose.org/symp2013/survey

Current status

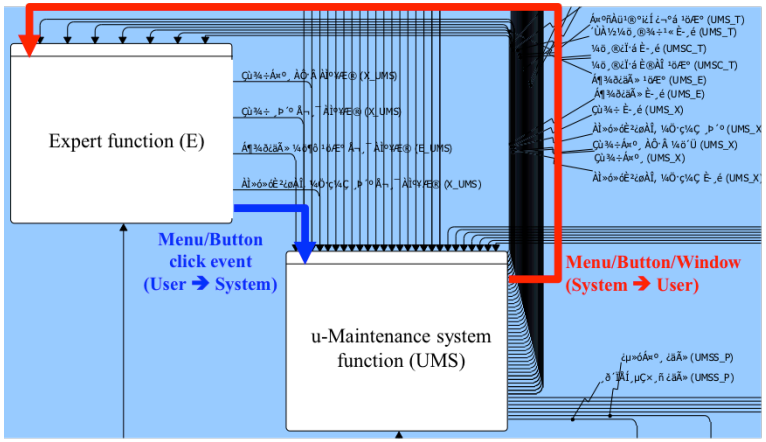
Architecture model developed & coded





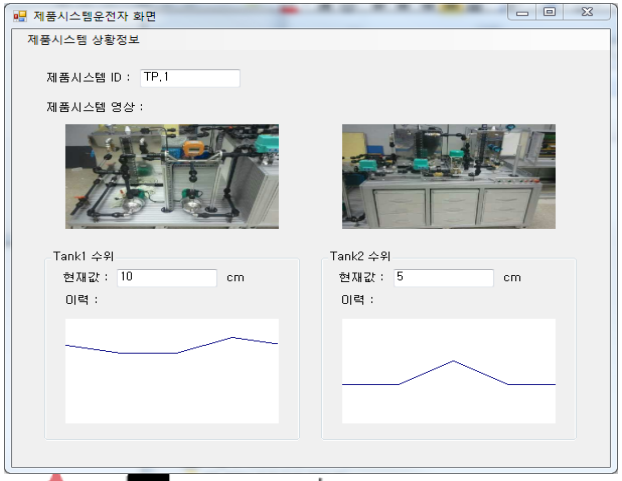


Basic proto developed



< An interaction in the functional architecture of the u-Maintenance system >

< UI of the expert client of the u-Maintenance system >



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Appendix. Literature survey

Existing researches concerning u-Maintenance systems

Major projects	Year	Considered ubiquitous technologies
ARVIKA [8] & ARTESAS [9]	1999 ~ 2006	Context-awareness, Augmented reality, HMD
PROMISE [10]	2004 ~ 2008	Smart embedded device, Mobile device
DYNAMITE [11]	2005 ~ 2009	Web service, Smart sensor, Smart tag, Agent, Mobile device
ARMAR [12]	2005 ~ Present	Context-awareness, Augmented reality, HMD
SmartFactoryKL [13]	2005 ~ Present	Context-awareness, Augmented reality, Mobile device
...	...	...

Major papers	Year	Considered ubiquitous technologies
Friedrich, W. [14]	2002	Context-awareness, Augmented reality, HMD
Ailisto, H. et al. [15]	2003	Context-awareness, Wearable computer
Lampe, M. et al. [16]	2004	Context-awareness, Augmented reality, Location tracking, Mobile device, Smart tag
Siltanen, P. et al [17]	2007	Augmented reality, Mobile device, Context-awareness
Tiwari, A. et al. [18]	2007	Wireless sensor network
Zeeb, E. et al. [19]	2008	Web service, Context-awareness, Location tracking, Networked embedded system, Mob ile device
Irigaray, A.A et al. [20]	2009	Web service, Smart sensor, Smart tag, Agent, Mobile device
Backman, J. and Helaakoski, H. [21]	2011	Mobile device, Location tracking, Smart tag
Ropp, T.D.et al. [22]	2011	Web service, Context-awareness, Augmented reality, Location tracking, Mobile device, S mart tag
Ziegler, J. et al. [23]	2011	Mobile device
Zhu, J. et al. [24]	2012	Augmented reality, Context-awareness
...	...	...

※ Abbreviation
- ARVIKA: Augmented Reality for Development, Production and Servicing
- ARTESAS: Advanced Augmented Reality Technologies for Industrial Service Applications
- PROMISE: PROduct lifecycle Management and Information tracking using Smart Embedded systems
- DYNAMITE: Dynamic Decisions in Maintenance
- ARMAR: Augmented Reality for Maintenance and Repair
- MOMA: Mobile technology to support maintenance efficiency

Analysis results for the existing researches

Research (in order of year)	Problems of the existing maintenance systems				Deliverable
	Insufficient equipment history or data	Poor system usability	Lack of technician's awareness of safety	...	
ARVIKA & ARTESAS	X	O	O	...	Technician support system using augmented reality
Friedrich, W.	X	O	O	...	Technician support system using augmented reality
Ailisto, H. et al.	X	O	X	...	Wearable context-aware terminal for technicians
PROMISE	O	X	O	...	Maintenance system using smart embedded device
Lampe, M. et al.	O	O	X	...	Smart toolbox and inventory for airplane maintenance
DYNAMITE	O	X	X	...	e-Maintenance system using ubiquitous technology
ARMAR	X	O	O	...	Technician support system using augmented reality
SmartFactoryKL	X	O	X	...	Technician support system using ubiquitous technology
Siltanen, P. et al	X	O	X	...	Technician support system using augmented reality
Tiwari, A. et al.	O	X	X	...	Condition-based maintenance system using wireless sensor network
Zeeb, E. et al.	X	O	X	...	Technician support system using context-awareness and web service
Irigaray, A.A et al.	O	X	X	...	Condition-based maintenance system using ubiquitous technology
Backman, J. and Helaakoski, H.	X	O	O	...	Maintenance scenario using mobile technology
Ropp, T.D.et al.	X	O	X	...	Airplane technician support system using ubiquitous technology
Ziegler, J. et al.	X	O	X	...	Technician support system using mobile technology
Zhu, J. et al.	X	O	X	...	Technician support system using augmented reality and context-awareness

The existing researches have been focused on the development of a particular technology and its laboratory prototype.

ref

Systems engineering process tailoring

Systems lifecycle process for general system [12]	
Technical	Stakeholder requirements definition process
	Requirements analysis process
	Architecture design process
	Implementation process
	Integration process
	Verification process
	Transition process
	Validation process
	Operation process
	Maintenance process
	Disposal process
Project	Decision management process
	…
Organizational project-enabling	…
Agreement	…

u-Maintenance system design methodology	
Requirement development	Field survey
	Select the target maintenance activity
	Select the target product operating activity
	Modeling of existing maintenance and product operating activity
	Modeling of u-Maintenance activity
	Gap analysis and User requirements derivation
	Evaluation of user requirements
	Selection of target user requirements
Solution development	Definition of system context
	Definition of system requirements
	Design of functional architecture
	Evaluate the functional architecture
	Design of physical architecture
	Evaluate the physical architecture

Gap analysis

Cap. Group		Existing maintenance and product operating activity				u-Maintenance activity				Gap		
Num	Name	Num	Name	Description	Relevant technology	Num	Name	Description	Relevant technology	Num	Name	Description
gr.3	Support for starting repair	aa.4	Find a failure (O)	The product operator finds a failure of a product.	null	ta.4	Find a failure (O)_u	The u-Maintenance system automatically finds a failure.	Context-awareness	g.2	Gap about the support for starting repair	• The system finds a failure automatically. • A corresponding technician is changed dynamically. The system decides automatically the most appropriate technician based on a situation whenever a failure occurs. •The system derives possible failure causes and solutions automatically, and this information is delivered to the technician.
		aa.5	Call a technician and Explain a situation (O)	The product operator calls a technician and explains a situation.	Phone	ta.5	Call a technician and Provide possible failure causes and solutions (O)_u	The u-Maintenance system automatically decides the most appropriate technician, possible failure causes, and solutions.	Context-awareness, Wireless sensor network, Real-time locating ms, Smart ph			
		aa.9	Recognize the failure (O)	The technician recognizes the failure by the explanation of the technician. He could identify the failure cause, depending on his expertise.	Phone	ta.9	Recognize the failure (O)	The technician recognizes the failure by the possible failure causes and solutions, provided by the u-Maintenance system.	Smart phone			
		aa.7	Find a failure (M)	The monitoring agent finds a failure in a particular product while monitoring several products.	null	ta.7	Find a failure (M)_u	The u-Maintenance system automatically finds a failure.	Context-awareness			
...	...	...	...	...	...	...	...	...	...	...	...	...

Example of user requirements derivation

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Philadelphia, PA
June 24-27, 2013

6W2H2V rule of Requirements description template.

Gap			User requirement											
Num	Name	Description	Num	Name	Who	Auxiliary verb	Verb	What (II)	What (I)	How (Technology)	How much	Why	When	Where
g.2	Gap about the support	• The system finds a failure automatically.	ur.3	Automatic detection of a failure in a product operating room	Product operator	shall	receive	-	the failure warning, detected by the system	via context-awareness	within 5 seconds	-	after a failure is detected	in a product operating room
g.2	Gap about the support for starting repair	• The system finds a failure automatically. • A corresponding technician is changed dynamically. The system decides automatically the most appropriate technician based on a situation whenever a failure occurs . •The system derives possible failure causes and solutions automatically, and this information is delivered to the technician	ur.3	Automatic detection of a failure in a product operating room	Product operator	shall	receive	-	the failure warning, detected by the system	via context-awareness	within 5 seconds	-	after a failure is detected	in a product operating room
			⇨	Automatic decision of a corresponding technician in a central control center	Monitoring agent	shall	receive	-	The information on the most appropriate technician, decided by the system	via real-time locating system and context-awareness	within 5 seconds	-	after a failure warning is received	in a central control center
			ur.5	Automatic decision of a corresponding technician in a product operating room	Product operator	shall	receive	-	The information on the most appropriate technician, decided by the system	via real-time locating system and context-awareness	within 5 seconds	-	after a failure warning is received	in a product operating room
			ur.6	Automatic identification of possible failure causes and solutions in a central control center	Monitoring agent	shall	receive	-	the possible failure causes and solutions, derived by the system	via context-awareness and wireless sensor network	within 5 seconds	-	after a failure warning is received	in a central control center
			…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Types of maintenance [38]

Maintenance activity	Description
Reactive maintenance (Breakdown maintenance)	• Allow a product to run to failure • Repair or replace damaged product when obvious problems occur
Preventive maintenance (Time-based maintenance)	• Schedule maintenance activities at predetermined time intervals • Repair or replace damaged product before problems occur
Predictive maintenance (Condition-based maintenance)	• Schedule maintenance activities when operational conditions warrant • Repair or replace damaged product before obvious problems occur
Reliability centered maintenance (Proactive maintenance)	• Utilize predictive/preventive maintenance techniques with root cause failure analysis to detect and pinpoint the precise problems • Include potential product redesign or modification to avoid or eliminate problems from occurring

A1.7.1 사용자 요구사항의 우선순위 평가

- **기술 구현가능성, 경제성, VOC의 평가결과를 종합**하여 사용자 요구사항의 우선순위를 평가하는 업무
  - Why? u-Maintenance 시스템의 구축 목적에 따라 강조되어야 할 측면이 바뀌어야 함
  - Why? 장기간의 로드맵 개발: 경제성↑, 단기간의 시스템 구축: 기술 구현가능성나 VOC↑

사용자 요구사항 (UR; User requirement)		기술 구현가능성			경제성			VOC			우선순위
번호	UR 이름	원래 값	변환 값	가중 값 (0.3)	원래 값	변환 값	가중 값 (0.3)	원래 값	변환 값	가중 값 (0.4)	
ur.1	중앙통제센터에서 모니터링	7	1.0	0.4	7.0	1.0	0.4	1	1	0.2	1.0
ur.6	중앙통제센터에서 가능한 이상상황 원인과 솔루션 자동 확인	5.5	0.7	0.3	4.0	0.6	0.2	1	1	0.2	0.7
ur.7	제품시스템 운전실에서 가능한 이상상황 원인과 솔루션 자동 확인	5.5	0.7	0.3	4.0	0.6	0.2	1	1	0.2	0.7
ur.2	중앙통제센터에서 이상상황 자동 발견	4	0.5	0.2	1.8	0.3	0.1	1	1	0.2	0.5
ur.3	제품시스템 운전실에서 이상상황 자동 발견	4	0.5	0.2	1.8	0.3	0.1	1	1	0.2	0.5
ur.8	중앙통제센터에서 이상상황 알림	4	0.5	0.2	1.8	0.3	0.1	1	1	0.2	0.5
ur.9	제품시스템 운전실에서 이상상황 알림	4	0.5	0.2	1.8	0.3	0.1	1	1	0.2	0.5
ur.12	가능한 이상상황 원인과 솔루션 제공	3.4	0.3	0.1	1.2	0.2	0.1	1	1	0.2	0.4
ur.18	수리작업정보 자동 제공	3	0.3	0.1	0.8	0.1	0.0	1	1	0.2	0.4
ur.13	가능한 이상상황 원인과 솔루션 자동 적응	2.5	0.2	0.1	0.5	0.1	0.0	1	1	0.2	0.3
ur.17	추가정보 검색/획득	4	0.5	0.2	1.8	0.3	0.1	0	0	0	0.3
ur.11	이동 시 위험 요인 경고	3.4	0.3	0.1	1.2	0.2	0.1	0	0	0	0.2
ur.10	길 자동 안내	3.3	0.3	0.1	1.1	0.2	0.1	0	0	0	0.2
ur.15	정비전문가 조언 요청	3.3	0.3	0.1	1.1	0.2	0.1	0	0	0	0.2
ur.16	정비전문가와 정비기술자 간의 협업	3	0.3	0.1	0.8	0.1	0.0	0	0	0	0.2
ur.20	수리결과 자동 저장	3	0.3	0.1	0.8	0.1	0.0	0	0	0	0.2
ur.19	수리 중 위험 요인 경고	2.8	0.2	0.1	0.7	0.1	0.0	0	0	0	0.1
ur.4	중앙통제센터에서 정비기술자 자동 결정	2	0.1	0.0	0.2	0.0	0.0	0	0	0	0.0

[목표 사용자 요구사항 선정 예]♪