28th Annual INCOSE international symposium
Washington, DC, USA
July 7 - 12, 2018

Development Concepts of Smart Service System-based Smart Factory (4SF)

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Introduction

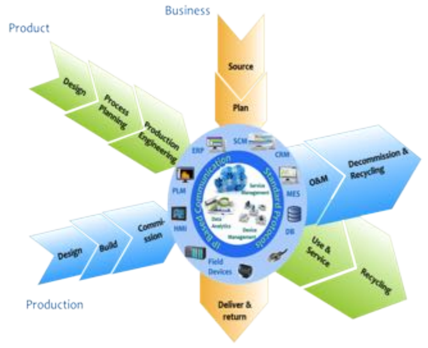
- Over the last decade, with the advent of promising tools such as enterprise systems, **manufacturing systems have evolved** to improve productivity and quality.

- Until now, to enhance productivity and quality, the complicated process management has been performed through application programs such as Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES).

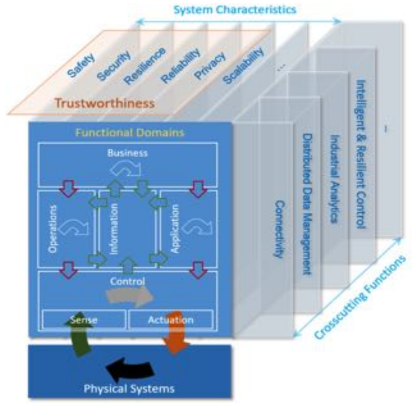
- A new paradigm on manufacturing industry is emerging**. This new paradigm, called “Smart Factory”, can be realized by introducing smart functions and technologies.**

Introduction

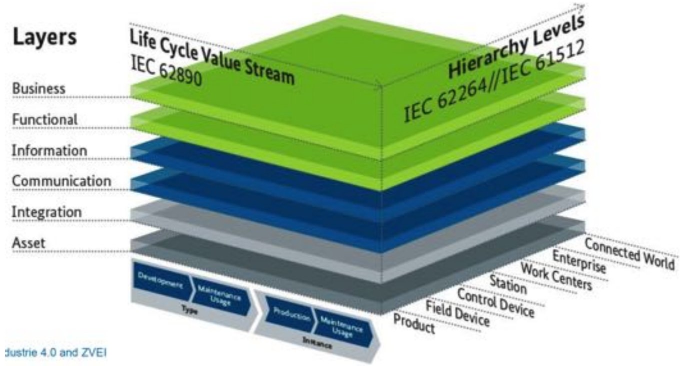
Architectures related to Smart Factory implementation, e.g. NIST, IIRA, RAMI, has already been established, and there is no significant technical or structural difference between these architectures. (Adolphs 2015, Lu 2016)
These architectures describe definitions of communication methods and services provided from Level 0 (Physical Process) to Level 4 (Business Logistic Systems) of ANSI/ISA 95.



NIST, Standards Landscape for Smart Manufacturing Systems



IIC, Industrial Internet Reference Architecture (IIRA 1.8)



Reference Architecture Model Industry(RAMI) 4.0

Introduction

- Even though these architecture suggest nice reference architecture of the final state of smart manufacturing systems, it is not easy to go to the final state.

- **<u>There is not a certain application process, to be applied to factories having different technology levels.</u>** (The different technology levels represent a factories may or may not have MES and/or ERP.)

- **<u>This study shows the ways of going to smart factory based on Smart Service System from existing conventional factories which have different technology levels.</u>**

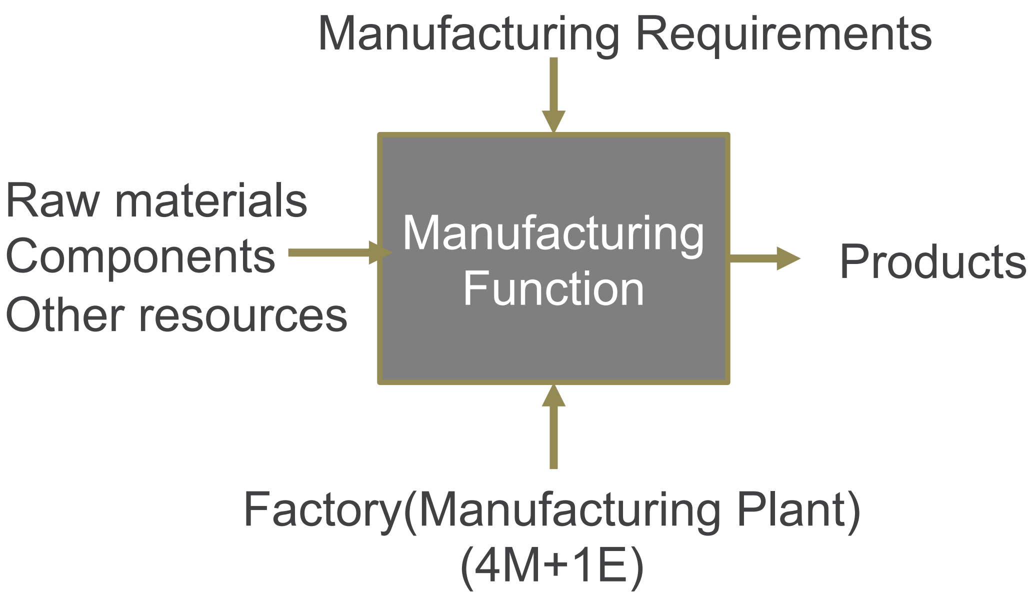
Smart Service System-based Smart Factory

Definition of Factory

Cheol Young Park, Kathryn Blackmond Laskey, Shelly Salim, Joong Yoon Lee, ***Predictive Situation Awareness Model for Smart Manufacturing***, Fusion 2017

General manufacturing description

- **Manufacturing** is the process of transforming (raw) materials into products based on the manufacturing requirements.
- **Factory(Manufacturing plant)** transform materials into products that address manufacturing requirements.
- The **measure of effectiveness(MOE)** of factory(manufacturing plant) is product **quality**, manufacturing speed(**time**) and manufacturing **cost**.
- These MOEs of manufacturing plant is determined mainly by **manufacturing factors** of 4M+1E.



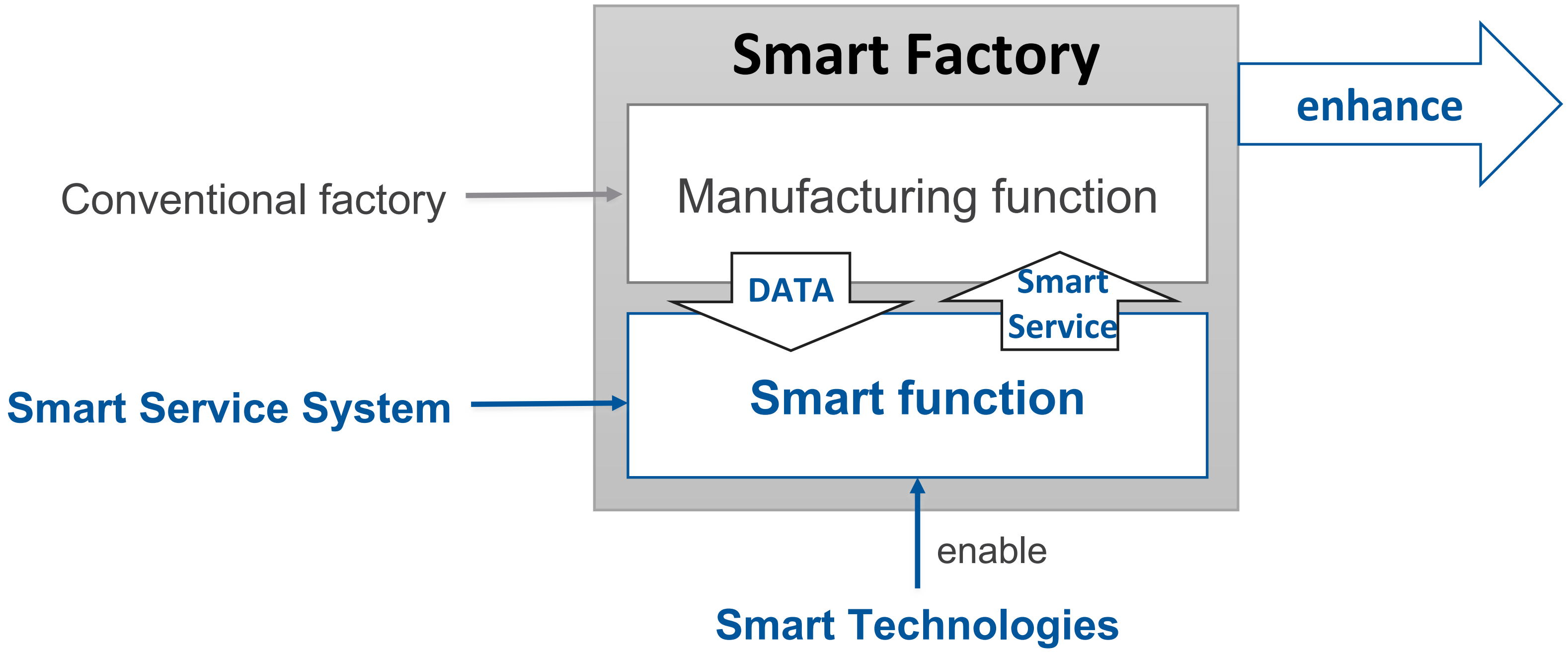
MOE of Manufacturing plant is
Quality, Time, Cost

Manufacturing factors: 4M + 1E [Suk-Keun Cha 2009]
(Man, Machine, Material, Method, Environment)

Definition of Smart Factory

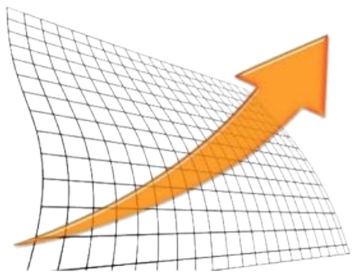
Cheol Young Park, Kathryn Blackmond Laskey, Shelly Salim, Joong Yoon Lee, ***Predictive Situation Awareness Model for Smart Manufacturing***, Fusion 2017

We define the smart factory as a **factory having smart functions based on smart technology** to enhance the **MOEs** of the factory.



MOEs of Manufacturing plant is

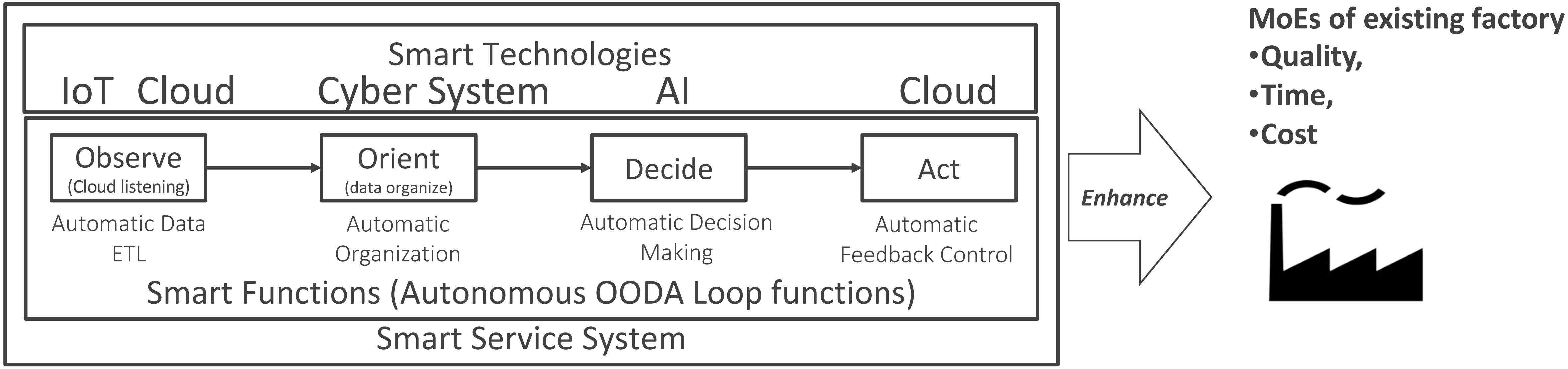
- Cost,
- Time,
- Quality



Smart Service System-based Smart Factory

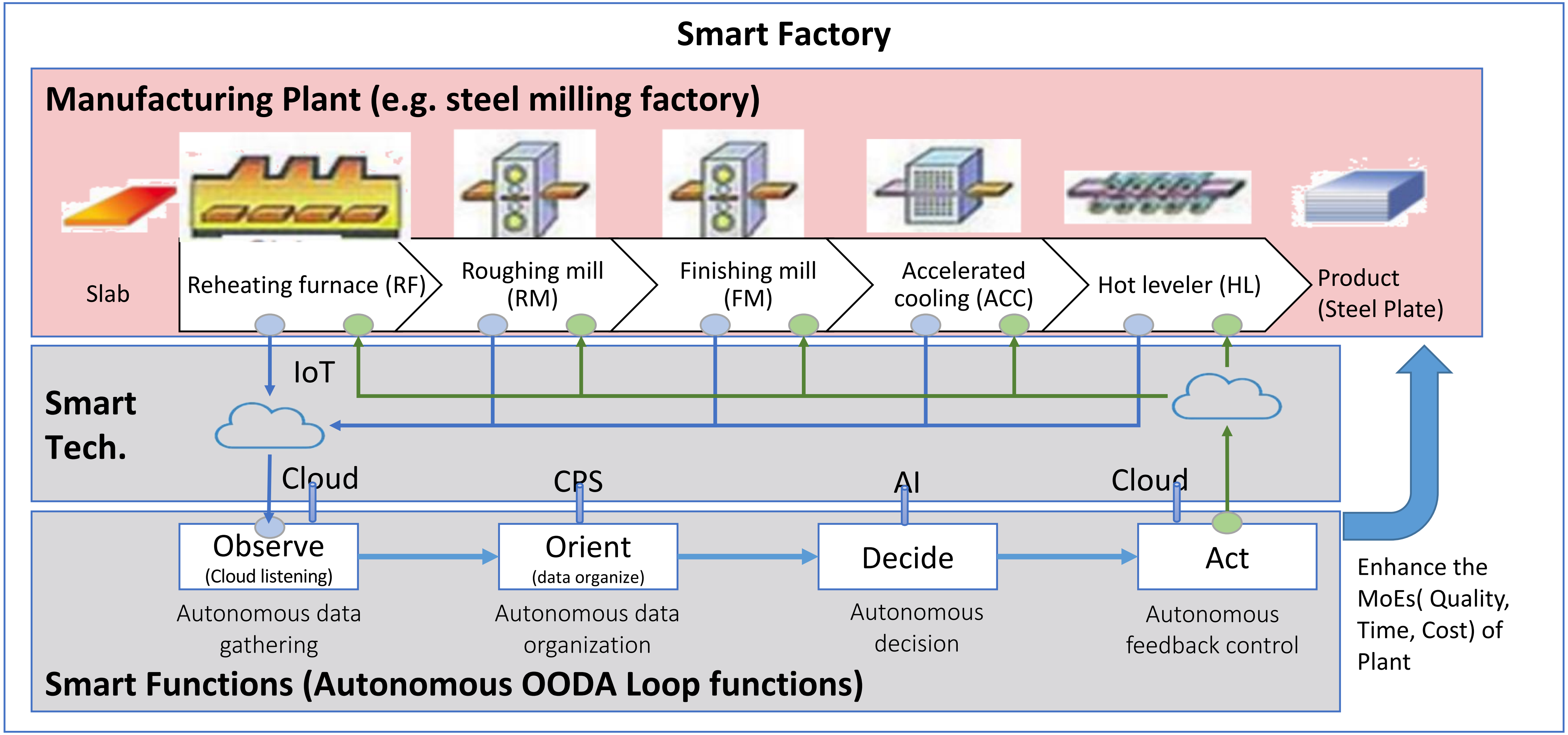
Cheol Young Park, Kathryn Blackmond Laskey, Shelly Salim, Joong Yoon Lee, ***Predictive Situation Awareness Model for Smart Manufacturing***, Fusion 2017

- We developed **Smart Service System concepts** as an additional system performing autonomous **OODA (Observe-Orient-Decide-Act) loop functions**, satisfying all the prerequisite smart functions of Smart Service Systems with smart technologies (Park 2017).



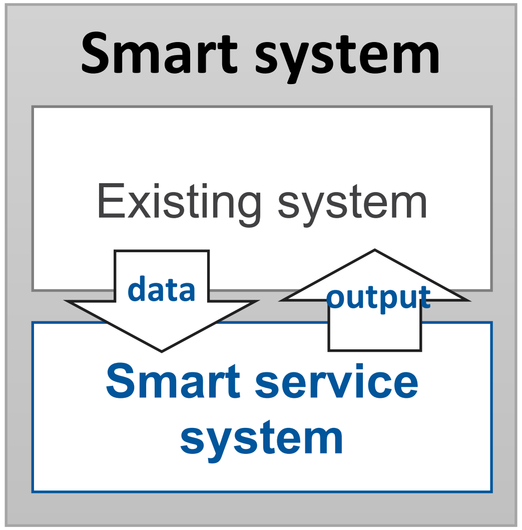
OODA loop: Boyd, J.R. (1976) COL USAF, Destruction and Creation, in R. Coram. Boyd New York, Little, Brown & Co, 2002

Example concept of smart steel milling factory



Smart Service System-based Smart Factory

- A Smart System could be developed based on a **combination of "Smart Service Systems" and "Existing Systems".**
- **In order to minimize the change of existing systems**, the Smart Service Systems can be mounted on the Existing Systems through the interface.
- In this case, the performance of Smart Service Systems depend on the followings;
  - Right data inputs from the existing system(Observe)
  - Right smart functions perform (Orient, Decision and Act)
  - Right outputs(recommended actions) send to the existing system



- The I/O of Smart Service System with Existing Systems is data and recommended actions.
- Where is data within an existing factory? And where the output should go?

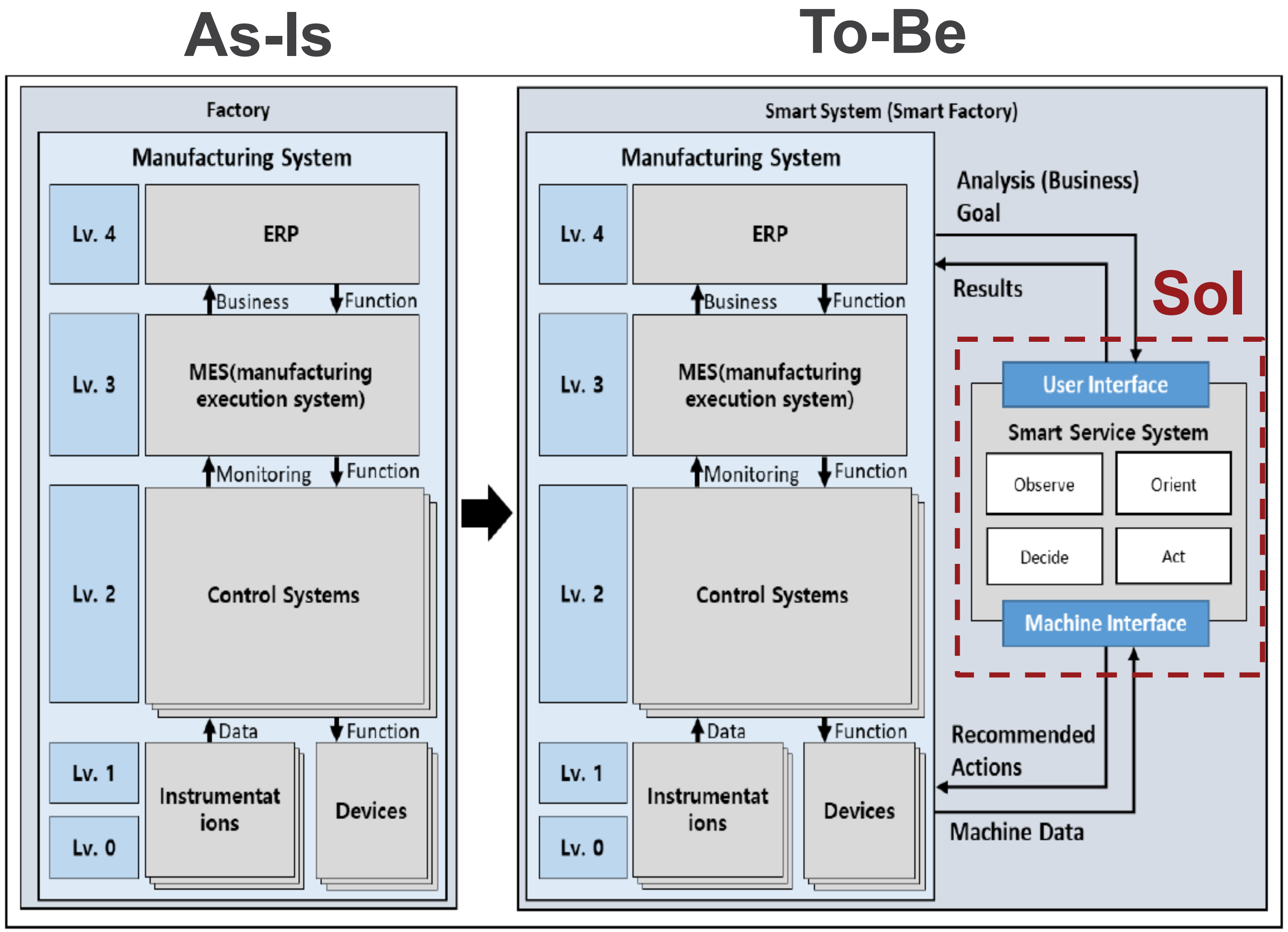
Smart Service System-based Smart Factory

Data of factory.

- The data of factories may come from Level 0 (Physical Process) to Level 4 (Business Logistic Systems) of ANSI/ISA 95.

System hierarchy

- SoI: The Smart Service System.
- Context: The Smart Factory
- Key Ext. System: Existing Plant



Development Concepts of Smart Service System-based Smart Factory (4SF)

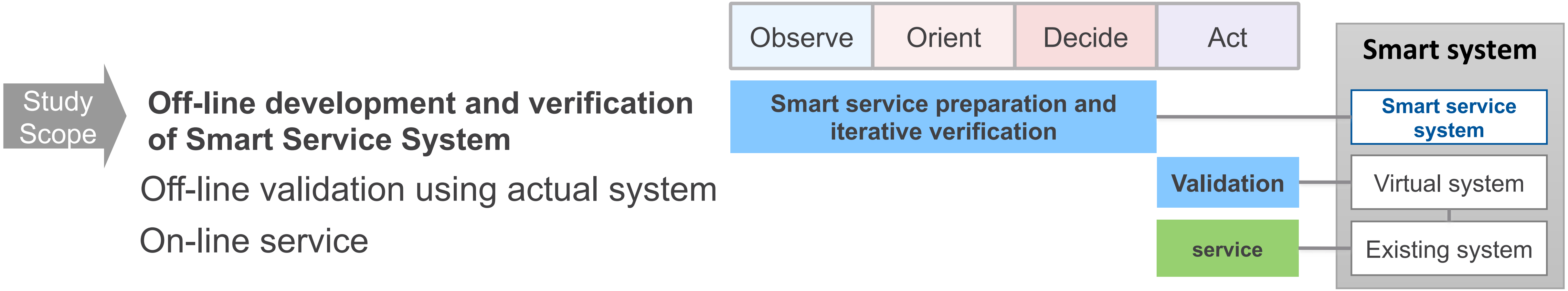
Development Concepts – Project Summary

- Mission: **Develop Smart Service System applicable for existing factories which may have different technology levels.**

- Key requirements:
  - Smart Service System should have minimal impact on the current manufacturing operation.
  - ➔ St.1 Service shall be done after validate the performance of Smart Service System
    - -- Off-line validation and on-line service
  - Smart Service System should have the function of identifying right data.
  - ➔ St.2 Service for domain implementer to identify right data shall develop
    - -- Using parameter model of the factory to identify right data.
  - Smart Service System should have reusability.
  - ➔ St.3 Develop Smart Service System as a component of smart factory.

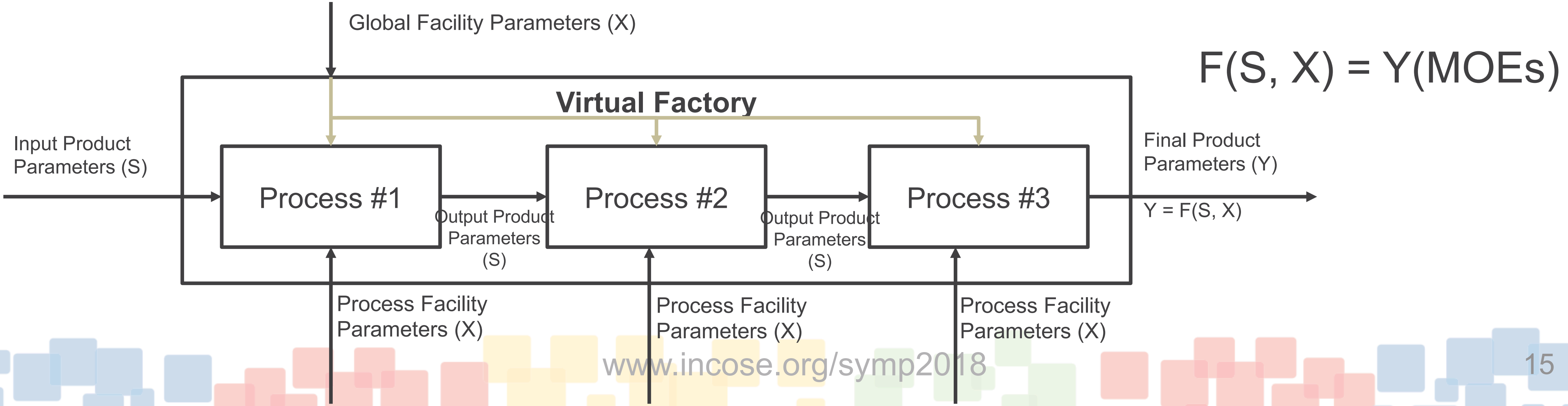
Development Strategy - Off-line validation and on-line service

- Implementation strategy of **Smart Factory** is to do on-line service after off-line validation of Smart Service System.
  - It is very important to minimize the impact of existing factory operations.
  - To accomplish this, the smart service system is developed and verified by using the data accumulated in the existing factory and installed in the existing factory.



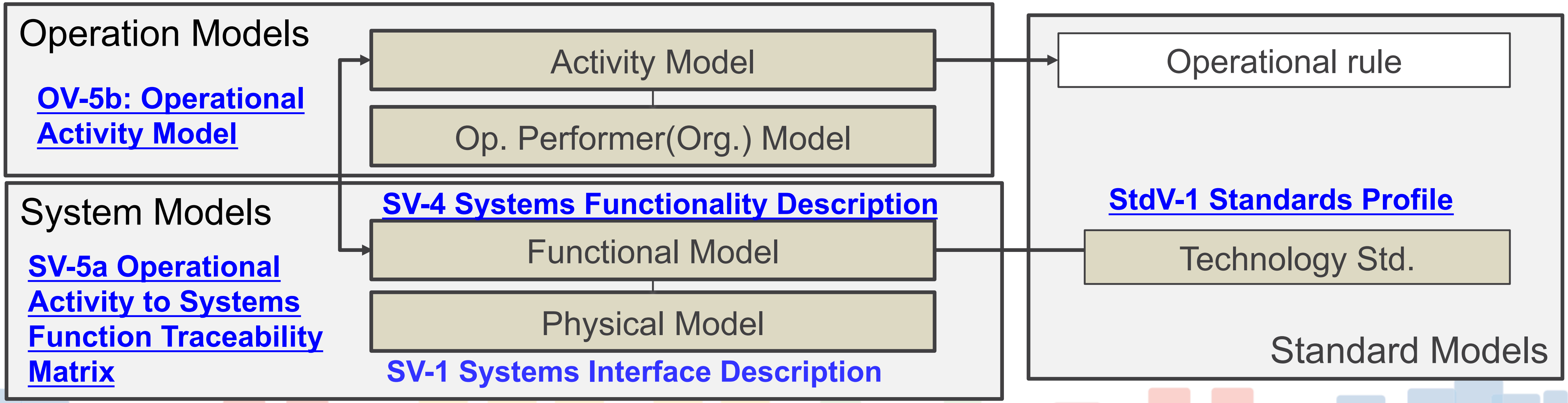
Development Strategy – Identify right data

- Using **parameter model of the factory** to identify right data.
  - Now a days in Korea, there are many attempts to develop smart factories but there are not many practically effective examples. I think this is the result of the difficulties to identify and using data related closely to factory MOEs among the huge number of factory data.
  - During performing the OODA function, it is important to identify and utilize data related to the factory's MOE. So, the domain specialist who implement the Smart Service System(hereafter domain implementer) have to identify the product and facility parameters which are related to factory MOEs. To do this, the Smart Service System should have the function of making a parameter model using block diagram.



Development Methods – Using architecture framework

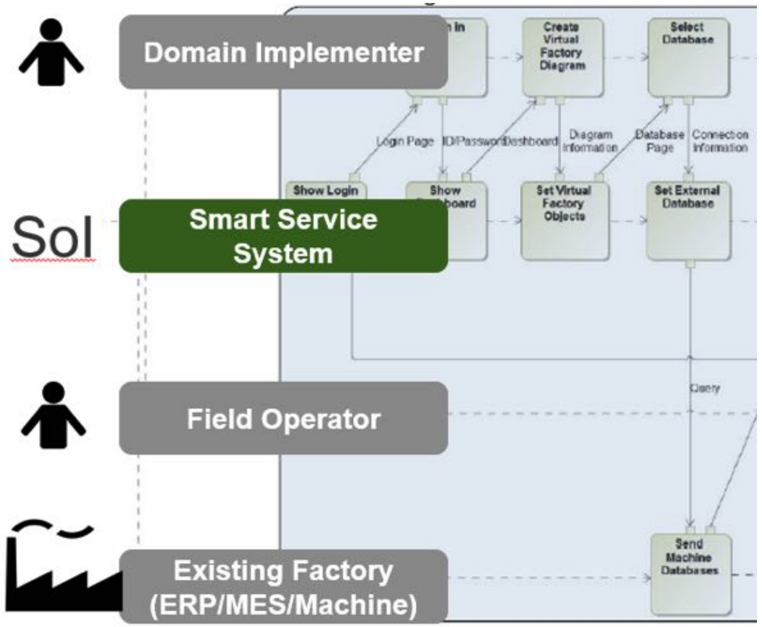
- Development methods is using the product of architecture framework(DoDAF of UAF) selectively to develop operational requirements, system requirements and technology requirements.
  - We developed **Operational Models, System Models, and Tehcnology Standard Models** for the Smart Service System.



Development Concepts

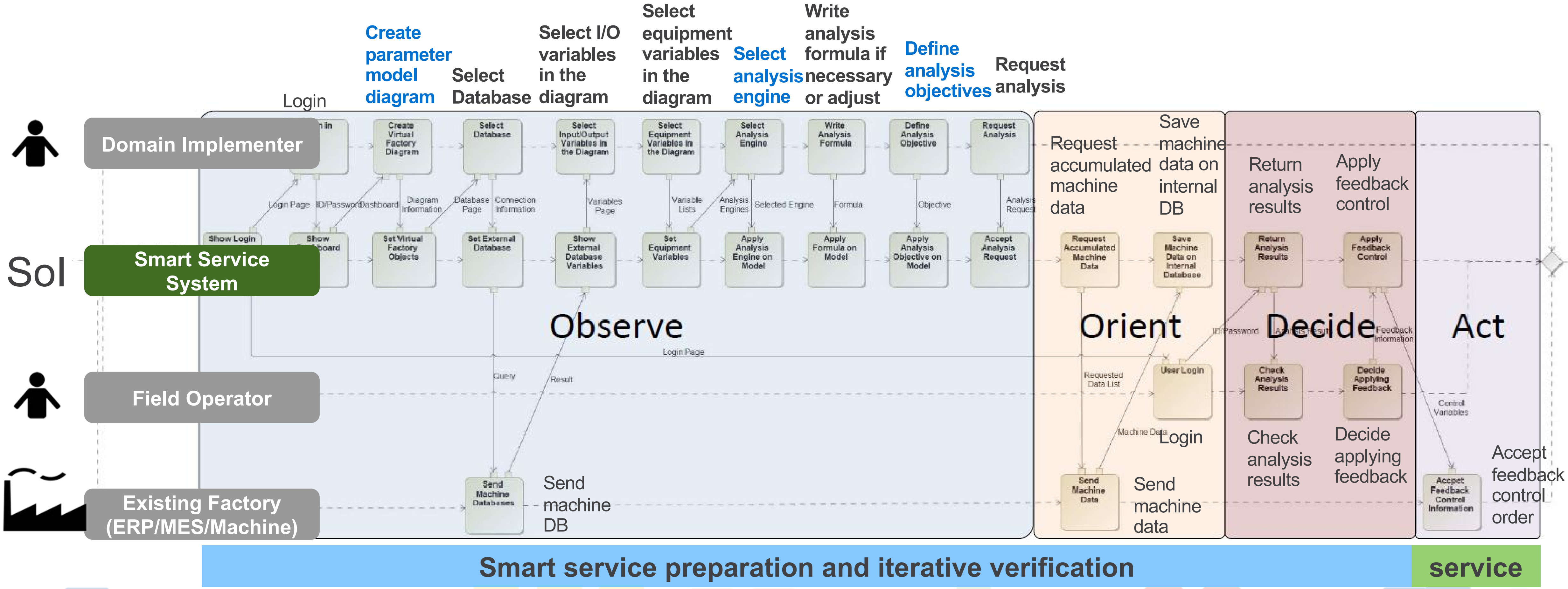
Operational Concept : Domain Implementer and Field Operator perform OODA process using Smart Service System.

- **Domain Implementers** could **create a parameter model** for an operation of initial Smart Service System. In this process, they could **select appropriate analysis module** and could set the analysis goals (Cost, Time, and Quality).
- **Smart Service System** performs the OODA loop according to Domain Implementers' setting basis. Smart Service System could handle data from the machines, and show results through the user interface or ERP systems.
- **Field Operators** could check the analysis results through the user interface and apply re-analysis of the results, or perform feedback control to machines.
- **Existing facilities:** Smart Service Systems could request or automatically collect existing system's data for analysis.



Development Concepts

- **Operational Activity Model(OV-5)**



SV-5a Operational Activity to Systems Function Traceability Matrix

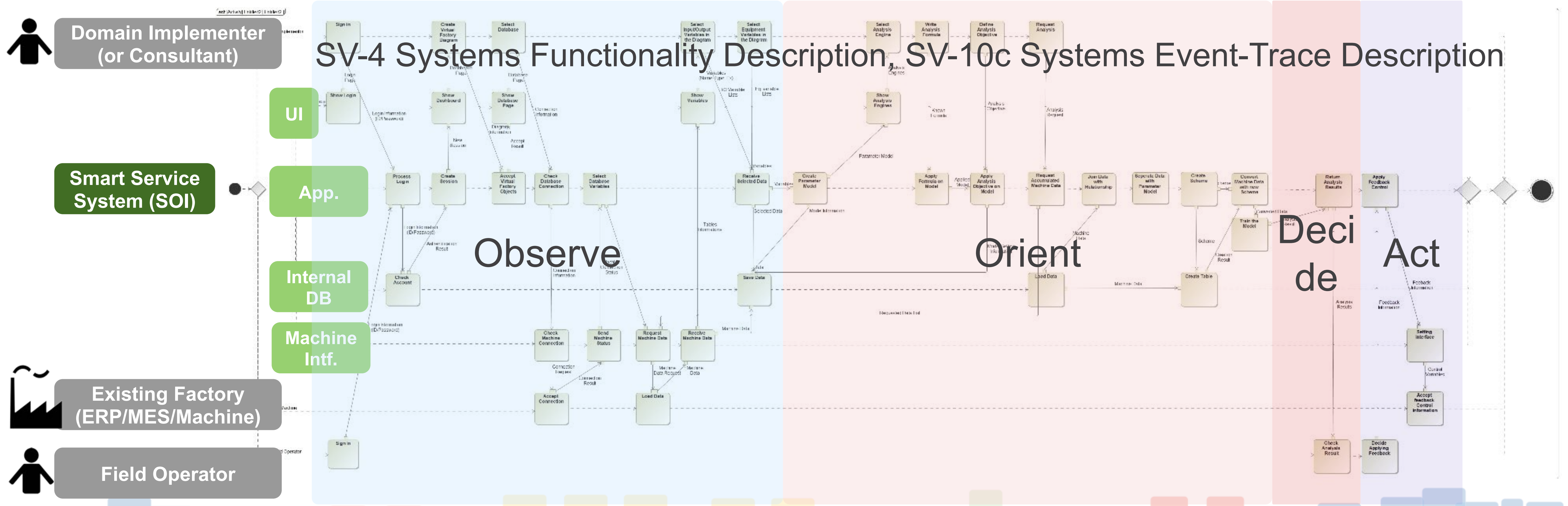
Systems Functions		Op. 1 Show Login	Op. 2 Show Dashboard	Op. 3 Set Virtual Factory Objects	Op. 4 Set External Database	Op. 5 Show External Database Variables	Op. 6 Show Equipment Variables	Op. 7 Show Analysis Engine	Op. 8 Apply Analysis Engine on Model	Op. 9 Apply Formula on Model	Op. 10 Apply Analysis Objective on Model	Op. 11 Accept Analysis Request	Op. 12 Request Accumulated Machine Data	Op. 13 Save Machine Data on Internal Database	Op. 14 Return Analysis Results	Op. 15 Apply Feedback Control
Func.1	Show Login	●														
Func.2	Process Login	●														
Func.3	Check Account	●														
Func.4	Create Session	●														
Func.5	Show Dashboard Page		●													
Func.6	Accept Virtual Factory Data			●												
Func.7	Show Database Page				●											
Func.8	Check Database Connection				●											
Func.9	Check Machine Connection				●											
Func.10	Send Machine Status				●											
Func.11	Request Machine Data				●											
Func.12	Select Database Variables					●	●									
Func.13	Show Variables					●	●									
Func.14	Receive Machine Data					●	●		●		●					
Func.15	Save Data					●	●		●		●			●		
Func.16	Create Parameter Model					●	●									
Func.17	Show Analysis Engine							●								
Func.18	Apply Formula on Model									●						
Func.19	Apply Analysis Objective on Model										●					
Func.20	Request Accumulated Machine Data												●			
Func.21	Join Data with Relationship											●				
Func.22	Separate Data with Parameter Model											●				
Func.23	Create Scheme											●				
Func.24	Create Table											●				
Func.25	Convert Machine Data with New Scheme											●				
Func.26	Train the Model														●	
Func.27	Load Data													●	●	
Func.28	Return Analysis Results														●	
Func.29	Apply Feedback Control															●
Func.30	Setting Interface															●

System functions are defined based on operational requirements.

Development Concepts

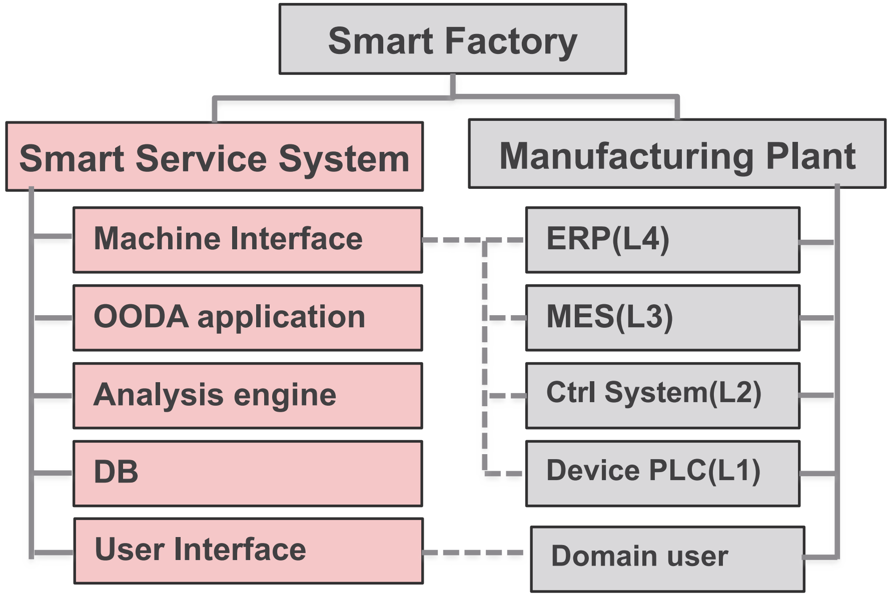
SV developed based on OV

- The **Functional Model** is divided into functional units that are implemented in the actual system to realize the Operational Model.



Development Concepts

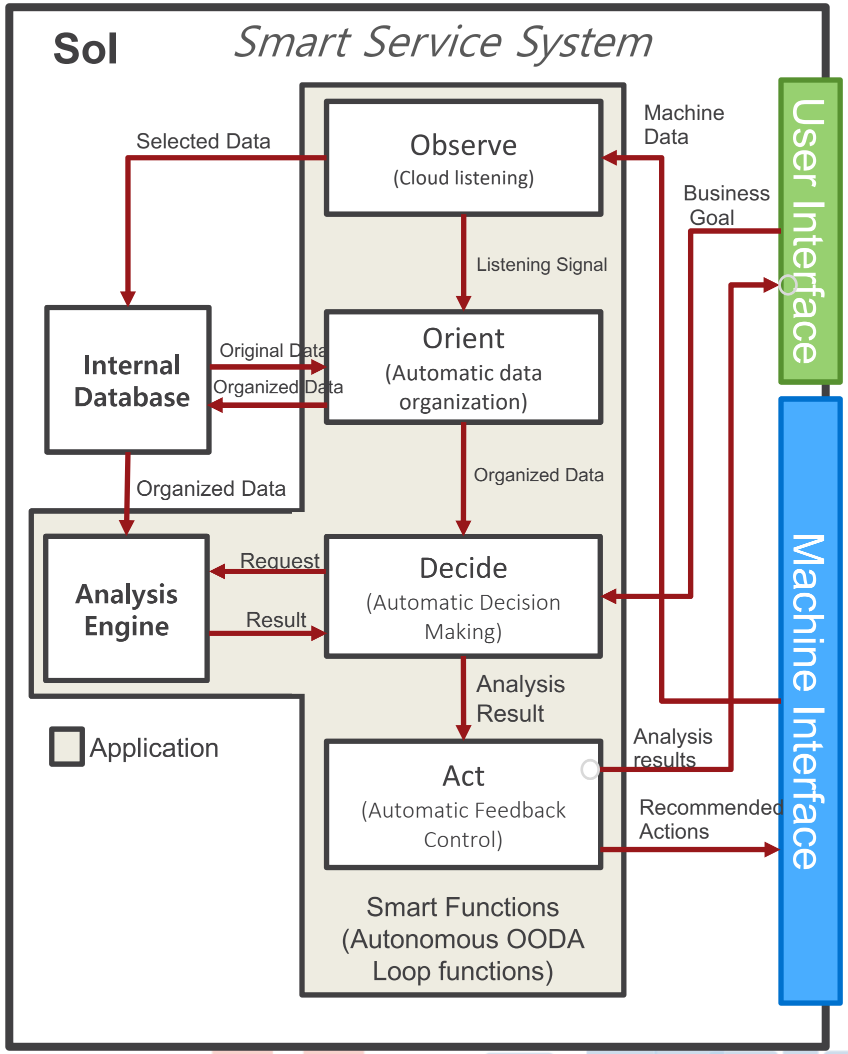
- System structure concept
  - System Context: Smart Factory
  - Interacting external systems: existing factories which may have different technology levels.
  - SoI : Smart Service System
    - Interfaces,
    - Application: **divide OODA functions and analysis engine** to use AI models selectively according to the characteristics of data
    - DB.



Smart Service System-based Smart Factory

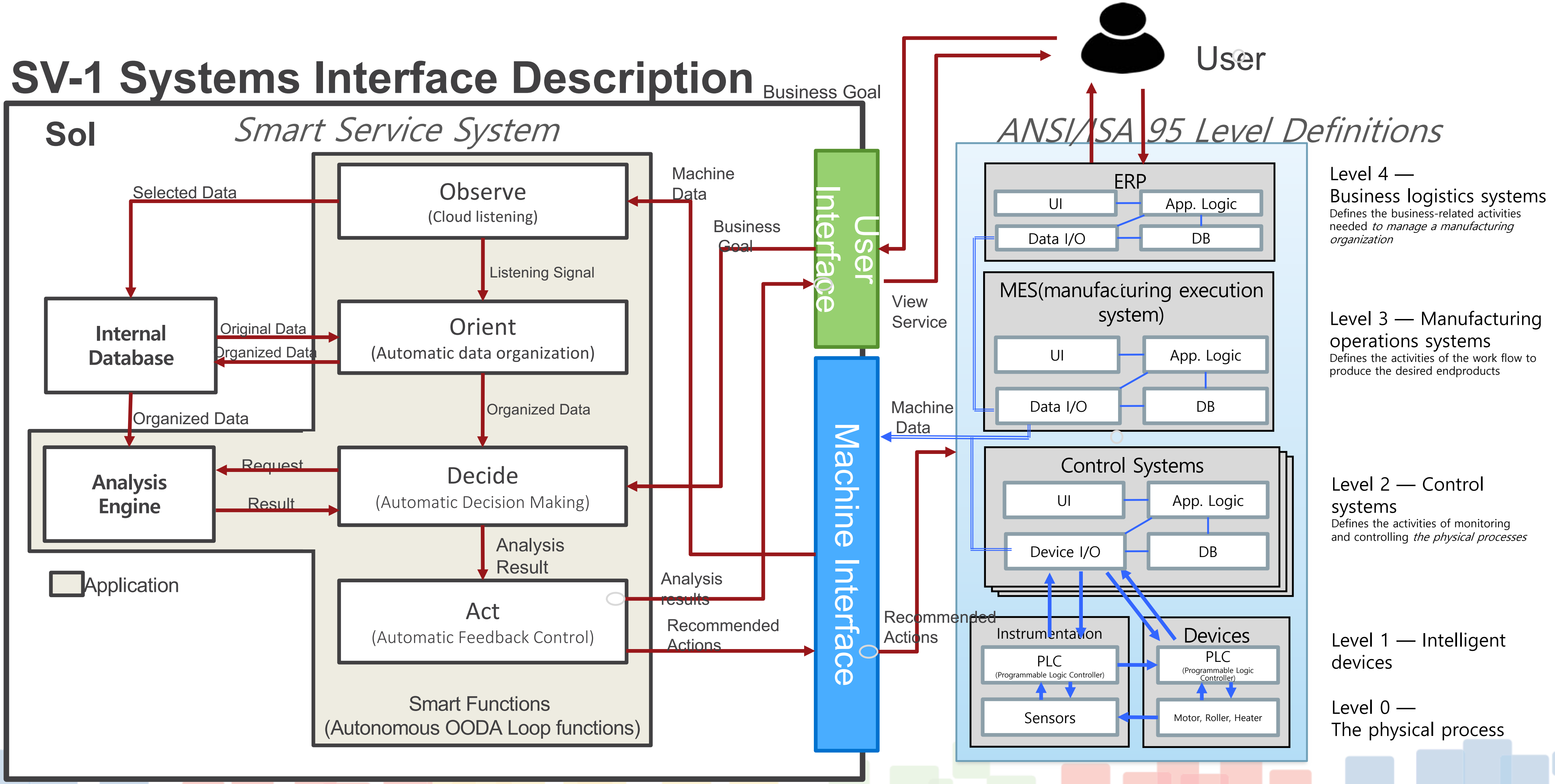
The components of Smart Service System.

- **User Interface**:
- **Machine Interface**:
- **OODA Applications**:
  - The application perform the OODA loop function and it must be able to interface with internal components such as Internal Database and Analysis Engine to execute it. **At Orient stage, appropriate Analysis Engines should be recognized and customize the data according to the selected engine.**
- **Analysis Engine**:
  - Analysis Engine is configured to be equipped with various machine learning engines(e.g. Multi-Entity Bayesian Network (MEBN) and Deep Neural Network (DNN) etc.).
- **Internal Database**:



Smart Service System-based Smart Factory

- **SV-1 Systems Interface Description**



Development Concepts

StdV-1

- For actual implementation, the applicable technology standards of each functions are listed as a Technology Standard Model.

01 User Interface
- Client Programming Languages
- Client Logic Processing
- Chart Libraries

02 Internal Database
- Database Management
- Database Connection

03 Client-Server Interface
- Client-Server Connection Language
- Client-Server Connection Methods
- Server Programming Languages

04 Analysis Logic Application
- Analysis Methods

05 Machine Interface
- Machine to Computer Connection Methods

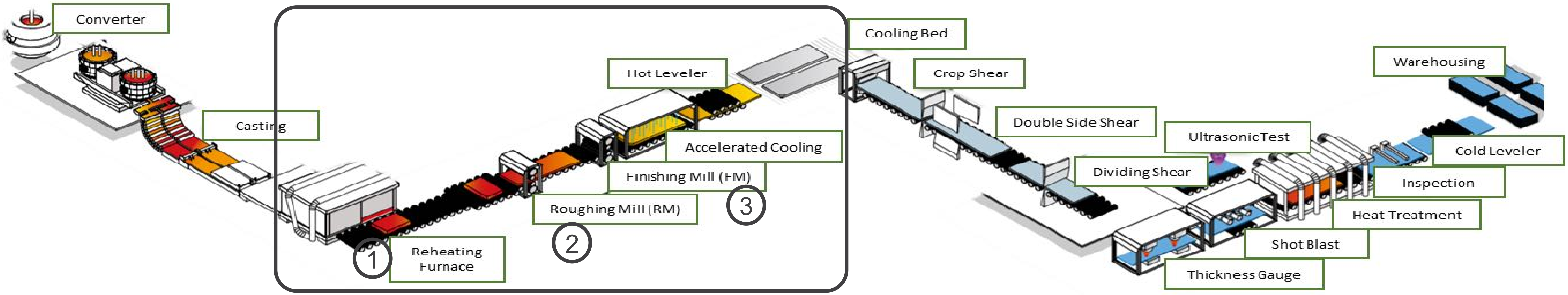
Group	Function	Function Name (Service Area)	Title of Standard
User Interface	Func.1	Show Login	[Client Programming Languages] • Function: JavaScript (ECMA-262 ECMAScript 2017) • Structure: HTML5 (WHATWG) • Design: CSS (RFC1328 text/css) [Client Logic Processing] • React, Vue.js, Angular.js [Chart Libraries] • Chart.js, D3.js, or Google Charts
	Func.4	Create Session	
	Func.5	Show Dashboard Page	
	Func.6	Accept Virtual Factory Data	
	Func.7	Show Database Page	
	Func.13	Show Variables	
	Func.17	Show Analysis Engine	
	Fnuc.28	Return Analysis Results	
Internal Database	Func.3	Check Account	[Database Management] • Relational Database Management System • NoSQL [Database Connection] • JDBC (Java Database Connectivity) • ODBC (Open Database Connectivity)
	Func.8	Check Database Connection	
	Func.12	Save Database Variables	
	Func.15	Save Data	
	Func.21	Join Data with Relationship	
	Func.22	Separate Data with Parameter Model	
	Func.23	Create Scheme	
	Func.24	Create Table	
	Func.25	Convert Machine Data with New Scheme	
	Func.27	Load Data	

Implementation

Application target - Thick steel plate mill plants

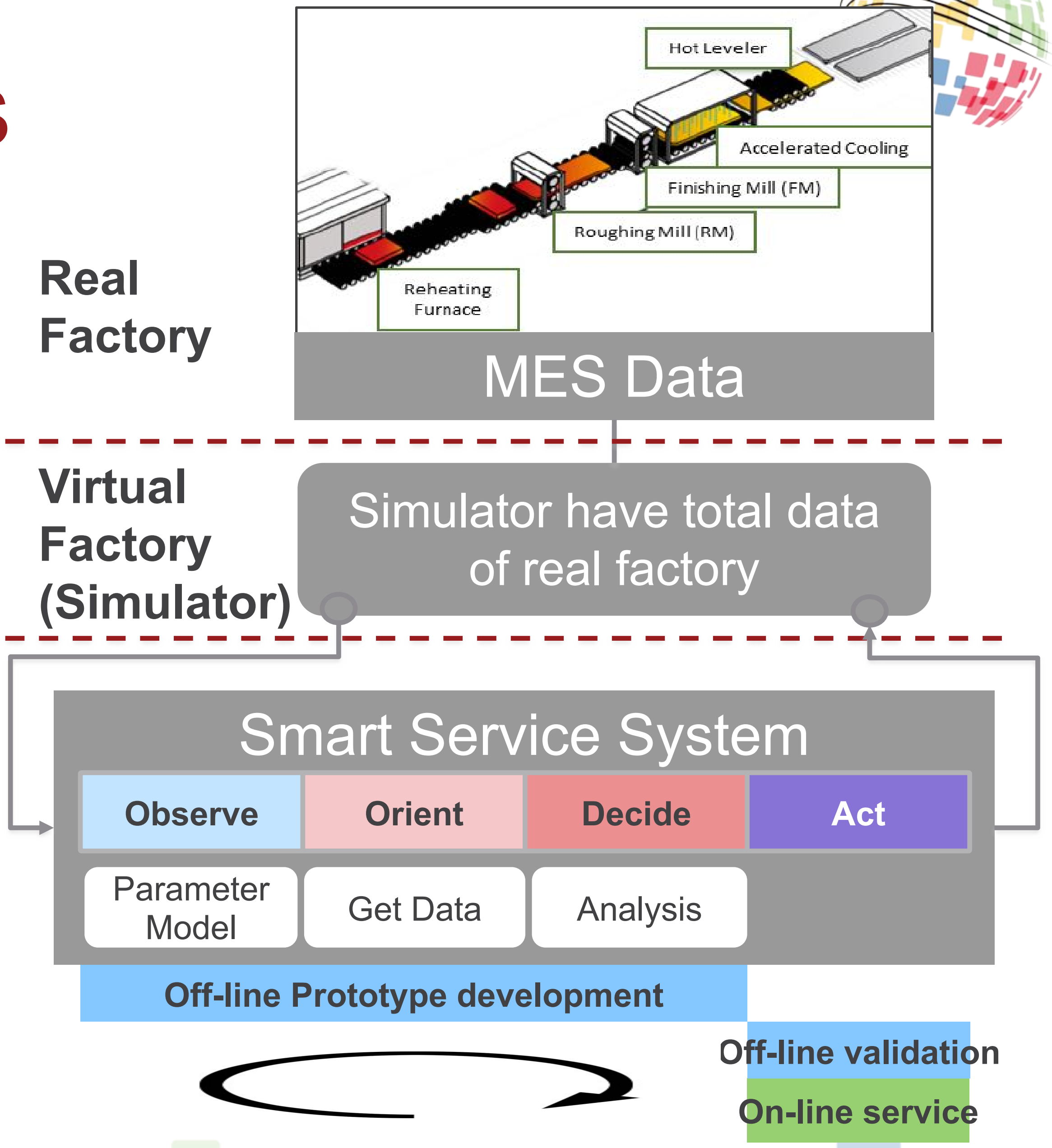
- POSCO has 18 main facilities for producing steel products. (POSCO, 2014).
- On steel manufacturing plants, **energy consumption costs** are the highest (Szemmelveisz 2014).
- **Smart Service System Application Factory: Thick steel plate mill plant**
- **Smart Service System Application Purpose:** As for the business goals of the manufacturing industry (cost, time, and quality), we aimed to **estimate energy cost and quality using smart service system** as a first step.

Thick steel plate mill plant



Implementation process

- **Off-line development**
  - Select implementation technology
  - Develop prototype of Smart Service System
- **Verify using existing data** of the thick steel plate mill plant
  - Domain implementer develop ‘Parameter Model’
  - Get the existing data of the selected parameters
  - Verify the performance of smart service



Implementation – Develop prototype

- Select implementation technology

Technology Items	Selected Technology
Client Programming Languages	JavaScript, HTML5, CSS
Client Logic Processing	React.js
Chart Libraries	D3.js
Database Management	MS-SQL (RDBMS)
Database Connection	Python DB-API (PEP-249)
Server-Client Connection Language	JSON (ECMA-262)
Server-Client Connection Methods	Socket.io
Server Programming Languages	Python
Analysis Methods	Multi-Entity Bayesian Network (MEBN)
Machine to Cloud(M2C) Connection M ethods	N/A (Data security policy)

- Develop prototype of Smart Service System

Prototype Smart Service System

Observe	Orient	Decide	Act

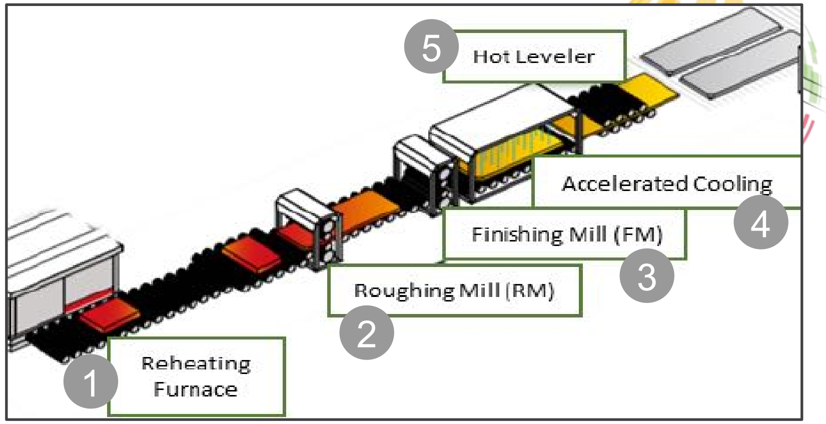
MEBN module was provided by SE/OR Lab. Of GMU

Thank your for your support!

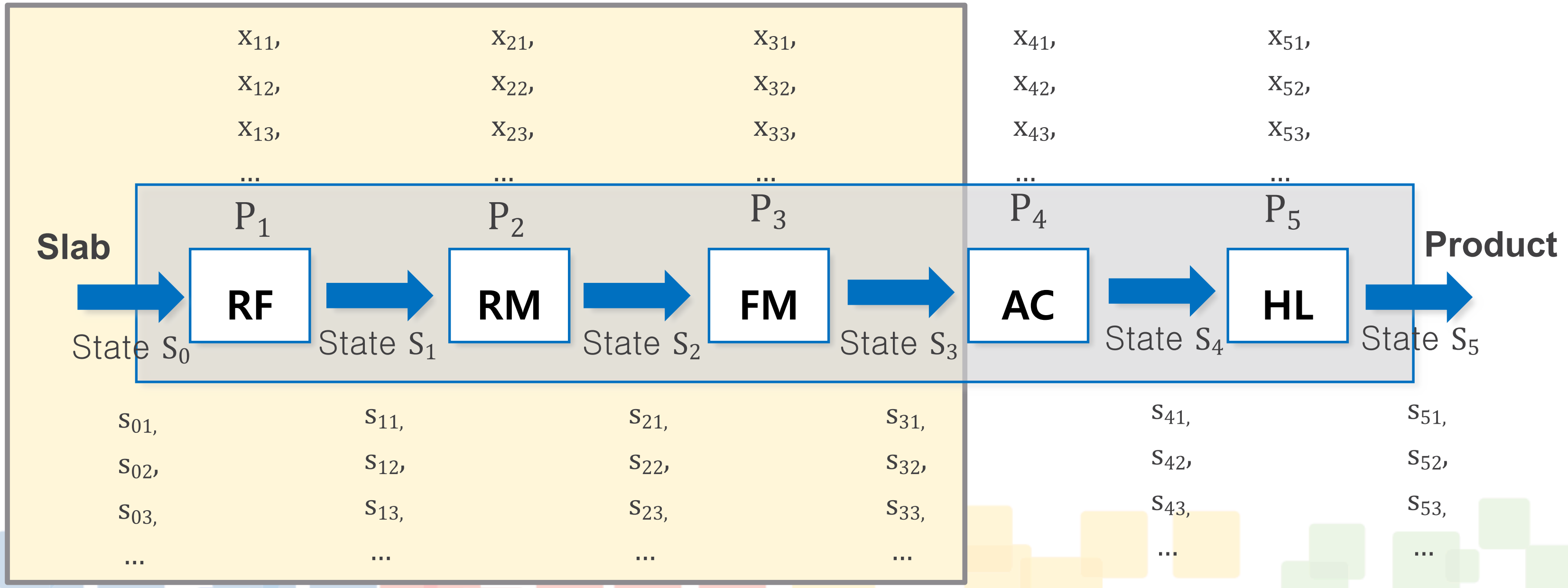
Prof. Kathryn Blackmond Laskey (GMU)
Dr. Cheol Young Park (GMU)
Shou Matsumoto (GMU)
Aakarshika Priydarshi (GMU)

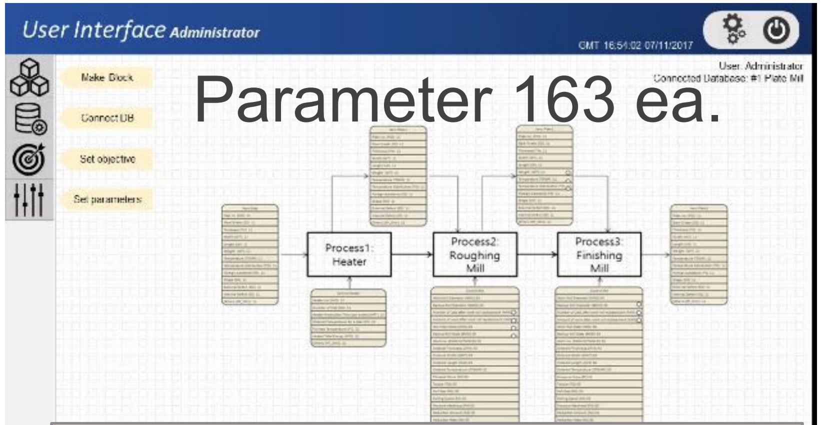
Implementation - Verification

- The Domain Implementer developed a **parameter model** by identifying process and product parameters that affect the energy cost of process and quality of product. (In this process, we could not study the parameters of the “④ accelerated cooling process” due to security problems.)



Thick steel plate mill plant	Data
① Reheating Furnace	O
② Roughing Mill(RM)	O
③ Finishing Mill(FM)	O
④ Accelerated Cooling	X
⑤ Hot Leveler	X



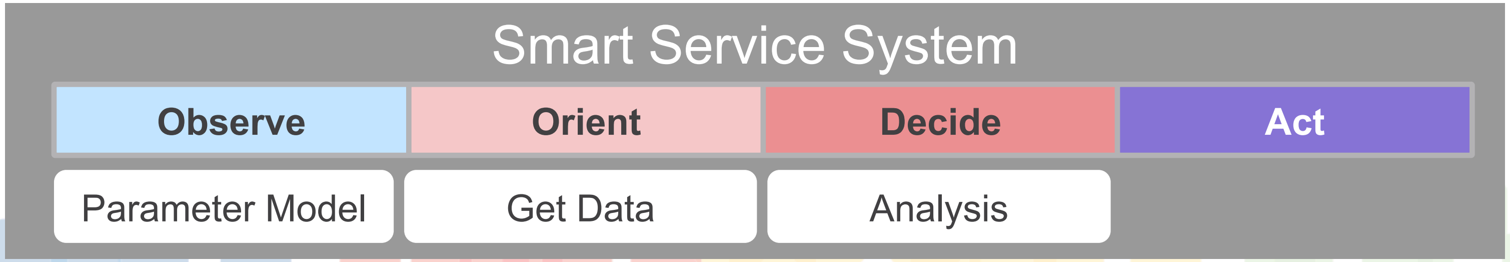


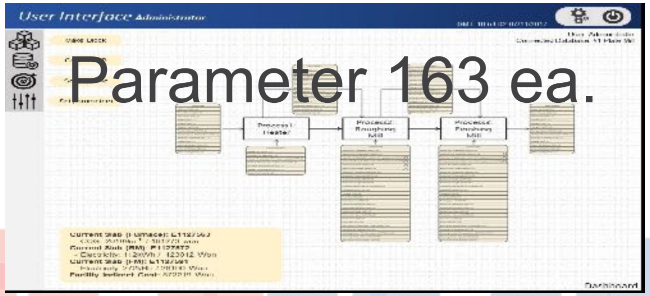
Implemented Parameter Model of **Thick steel plate mill plant**

Implementation - Verification

- **Estimation of energy cost:** Estimation of energy cost can be estimated by dividing each process. The number of parameters directly related to energy cost is relatively small (about 10), so **we developed a cost estimation model through statistical analysis** and used it to estimate the energy cost.

- **Quality estimation:** The 163 parameters was reflected in the parameter model, it was difficult to exclude items not related to quality. Therefore, quality estimation is beyond the scope of statistical analysis, so **we used machine learning through Multi-Entity Bayesian Network (MEBN) to estimate quality**.

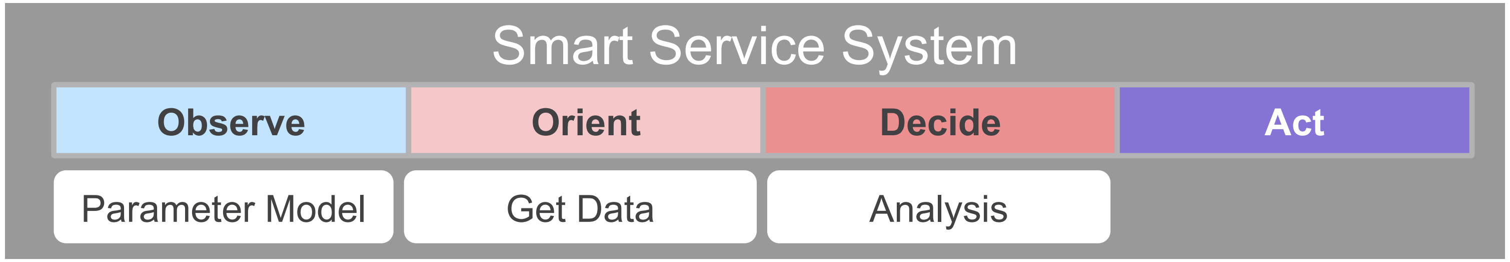


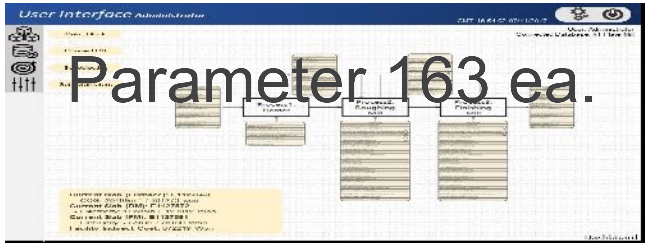


Implementation - Verification

- The data corresponding to the identified parameters were collected and used for analysis and machine learning & inference.
  - Gathered data: **4 months(2017.2~5) manufacturing data** (306,265 Row for 24,420 Slab.)
  - **Data used to estimate Energy(gas) cost** : **3 month data**(250,000 Row for ~20,000 Slab) was used for model development, **1 month data**(50,000 Row for ~4,000 Slab) was used for verification
  - **Data used to estimate Quality** : 163 parameter & 5 defect code of **12,760 slab** was used for machine learning and **100 slab** data was used for verification.

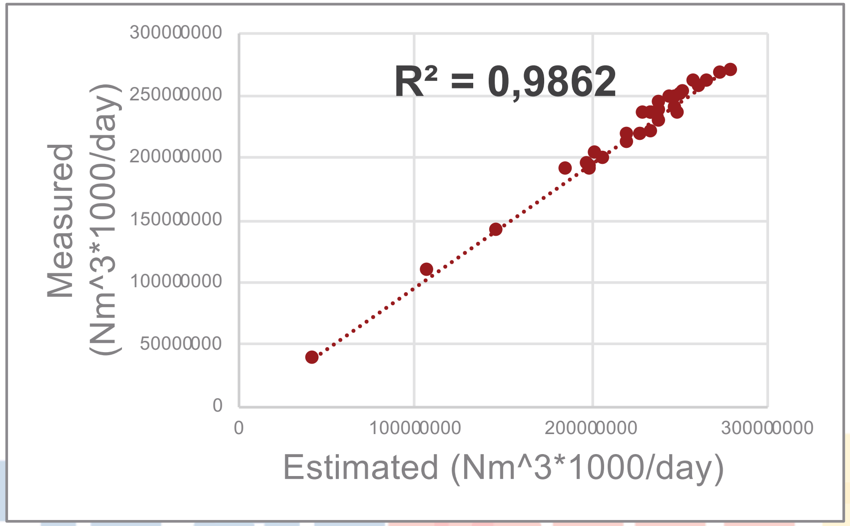
  (Very small data was used because of running speed of MEBN module)



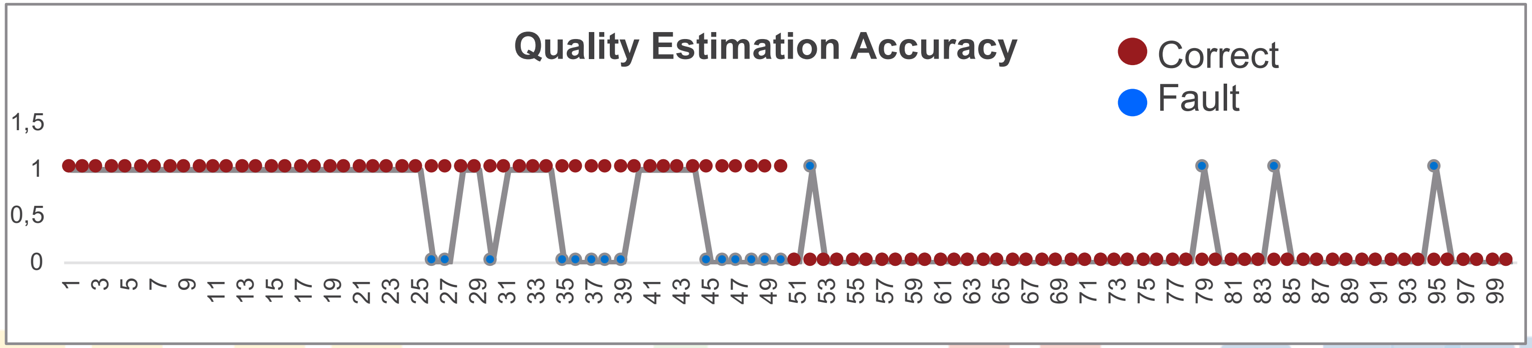


Verification results – Estimation accuracy

Cost	Quality
98.6%	82%



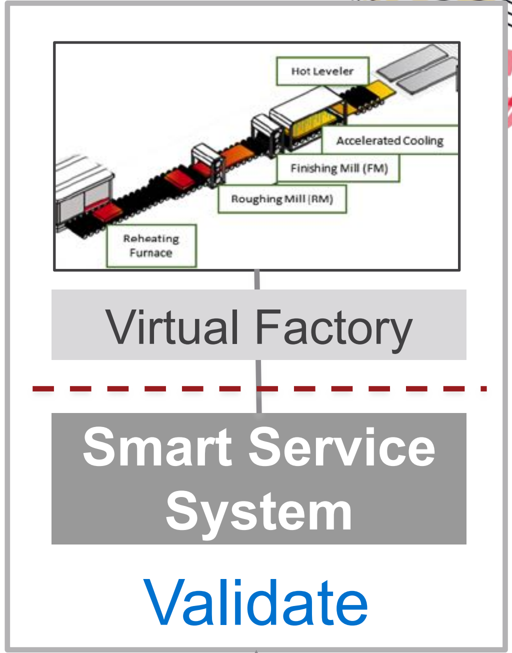
- Cost estimation accuracy is satisfied.
- Quality estimation accuracy is not satisfied.
  - Does not include cooling process data.
  - The number of learning data(12,760 slabs) is small because the MEBN module running speed is low.



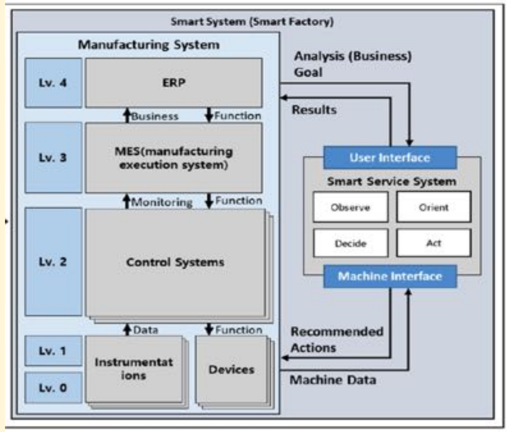
Conclusion and Future Works

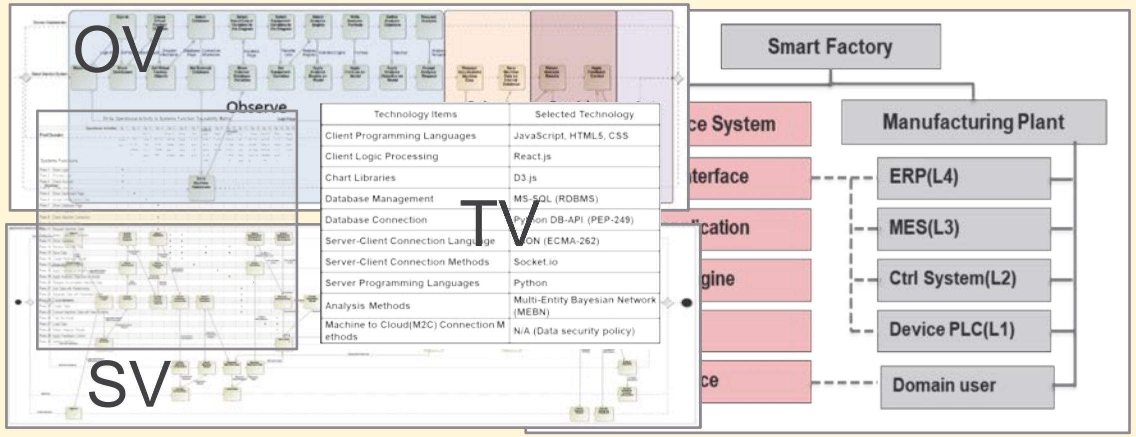
Conclusion

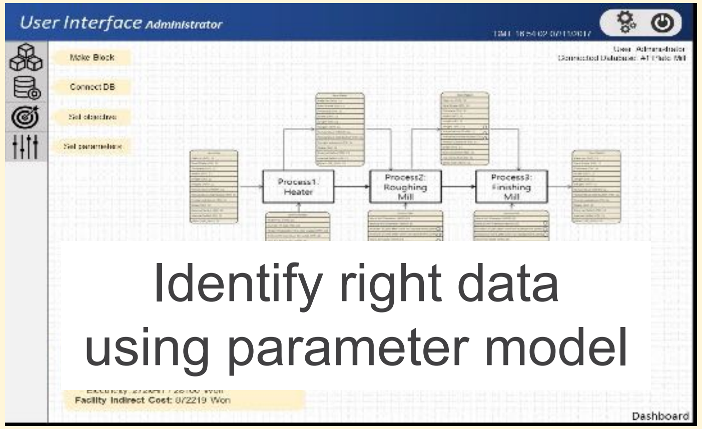
- This paper presented the concept of developing the Smart Factory based on Smart Service System.
  - For various technology levels of the existing factory
  - With minimize impact on current operation



Concept 4SF → System design using AF → Prototype

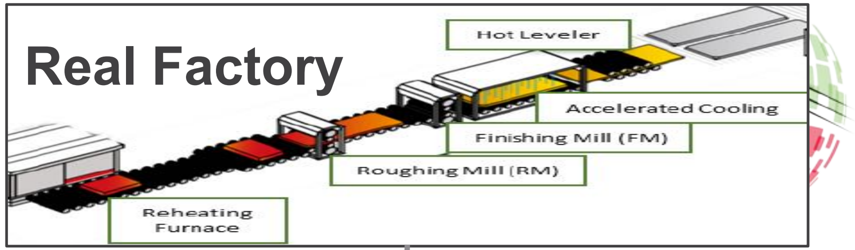


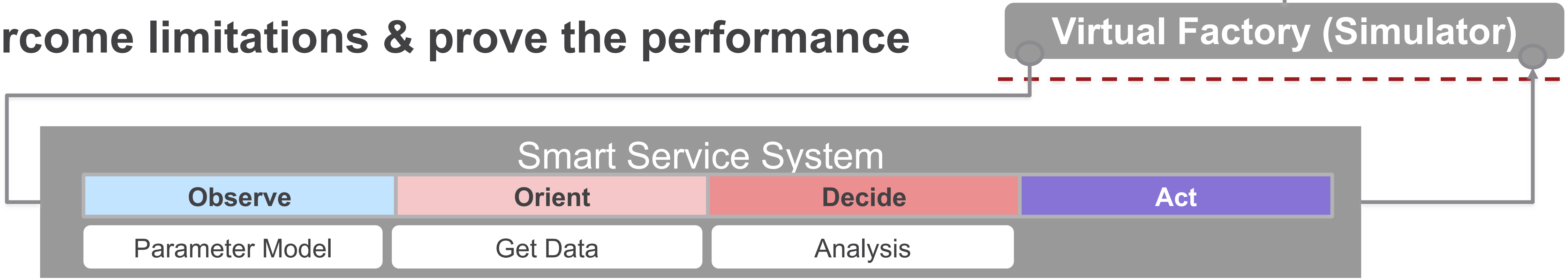




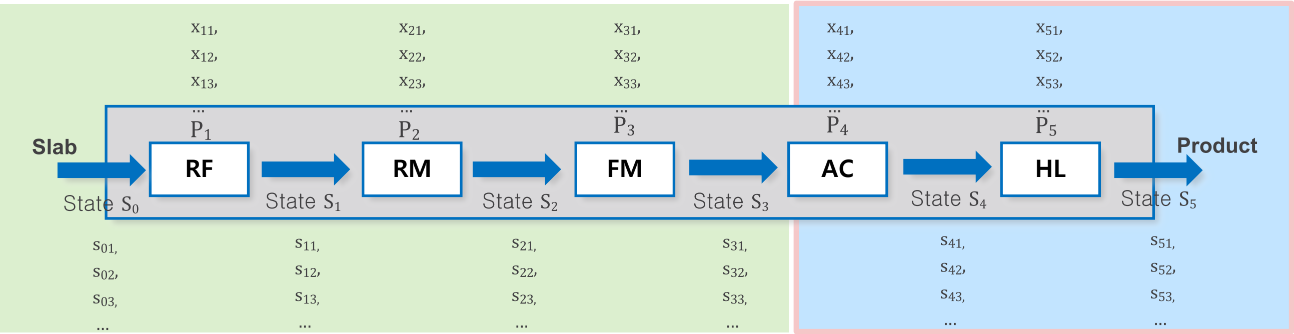
Future work – Near term

Overcome limitations & prove the performance

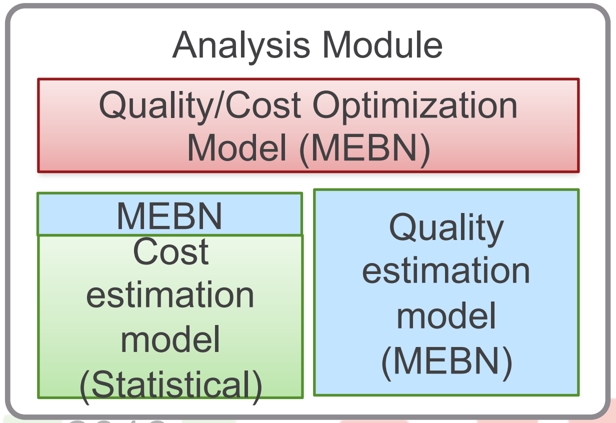




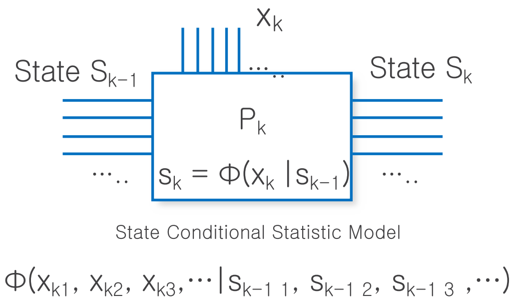
Extend the parameter model and acquire full data



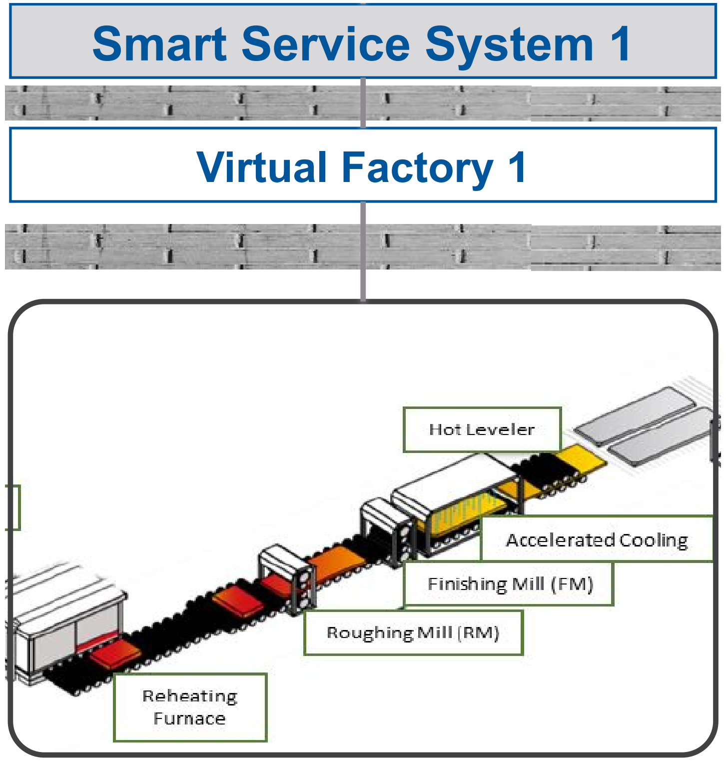
Develop Quality/Cost Optimization Model



Enhance MEBN module running speed



Future work – Long term



Thick steel plate mill plant

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ACKNOWLEDGMENTS: We appreciate the following colleagues for the initial research regarding Smart Service System-based Smart Factory (4SF).

Prof. Kathryn Blackmond Laskey (GMU)
Dr. Cheol Young Park (GMU)
Shou Matsumoto (GMU)
Aakarshika Priydarshi (GMU)

Prof. Seung-gap Choi (POSTECH)
Dr. Chang-ho Moon (POSCO)
Dr. Gang-hyek Choi (POSCO)