

Big Data Strategy for Supporting NPP Operation and Maintenance



Prof. JaeCheon Jung

KINGS

1 개 요

2 수행 단계 적용

3 사례 1 : 요건 관리 자동화

4 사례 2 : 사건 DB를 이용한 FMEA DB 생성

5 결론 및 향후 추진 내용

목적 및 방법

● 목 적

- 원전의 운전 및 정비 경험을 자동 분류 및 DB화 하여 동일 또는 유사 사건이 재발되지 않도록 운전/정비원을 지원하는 시스템 개발

● 방법론

- KINS OPIS, USNRC LER 등의 사건 이력을 조사하여 발생원인과 영향, 조치 사항을 DB화
- 수작업에 의한 DB 데이터 구축은 많은 전문 인력이 요구되므로 머신 러닝을 이용한 빅 데이터 처리

DB 검색 엔진 구현 개념

DB 검색 엔진 (OPIS, LER, NEI DB 등)

자연어 처리 모델

Feature Extraction

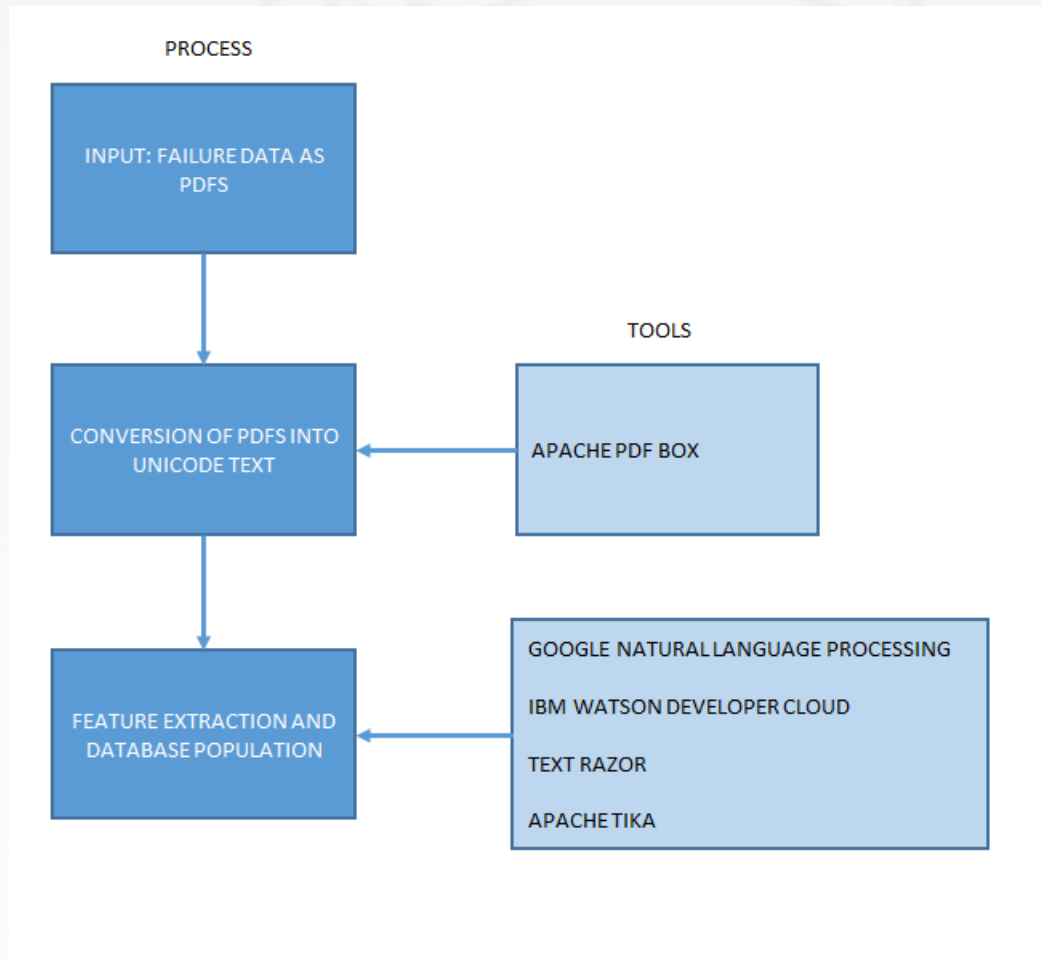
문서 관리 자동화

머신 러닝 Tools

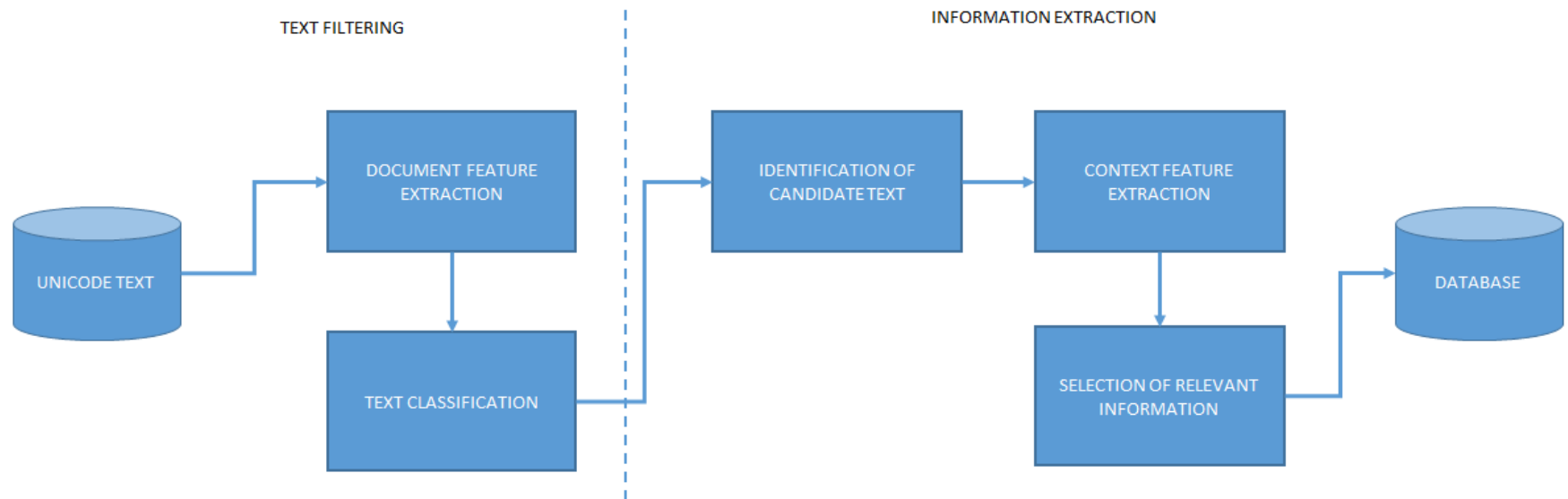
FMEA DB 생성 및 운전원/정비원 지원 자동화 시스템

원전 감시 시스템
데이터 인터페이스FMEA DB
자동 생성기운전 및 정비원
지원 인터페이스

DB 검색 엔진

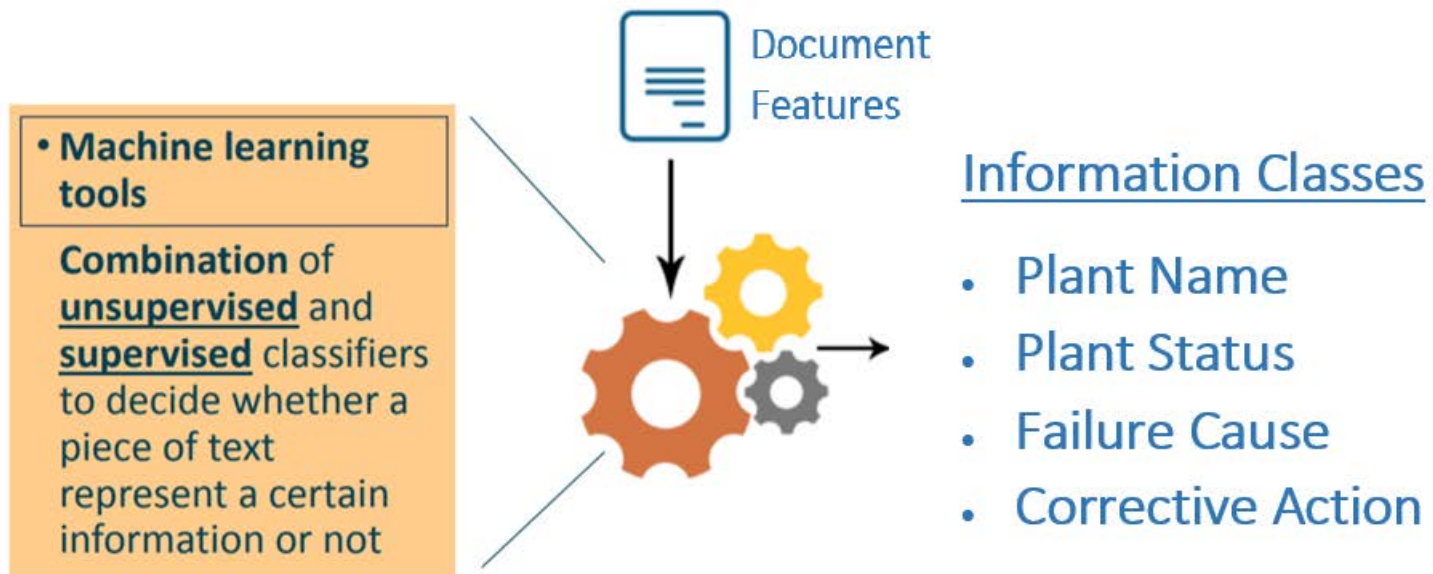


DB 검색 엔진 : Feature Extraction

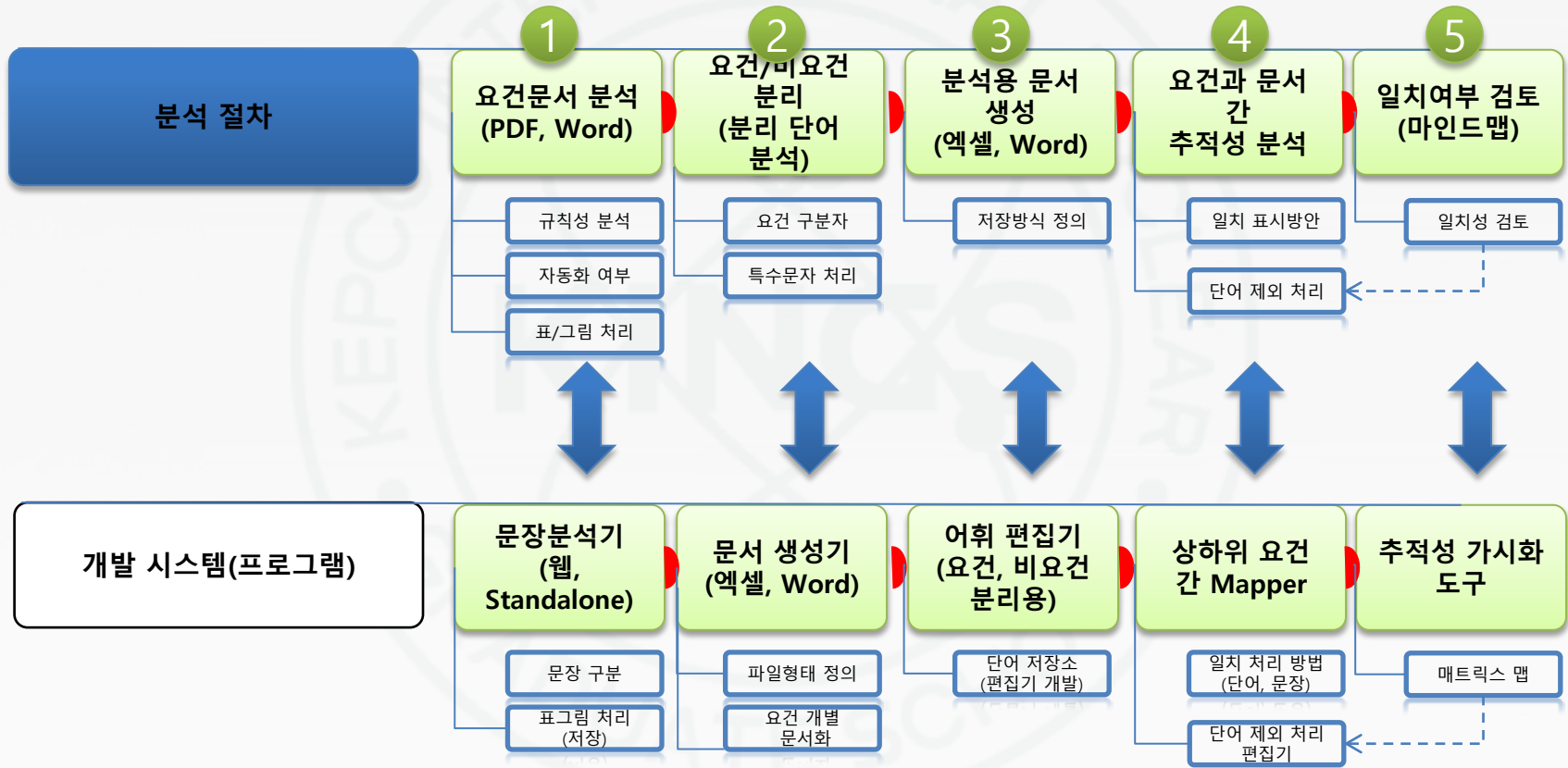


머신 러닝 도구

- 머신 러닝은 지침서를 이용한 정보의 유무를 판별하여 출력 제공
- Batch 예측 방법을 사용하고자 함
- IBM 왓슨, Google 자연어 처리, Text Razor 등 활용 가능

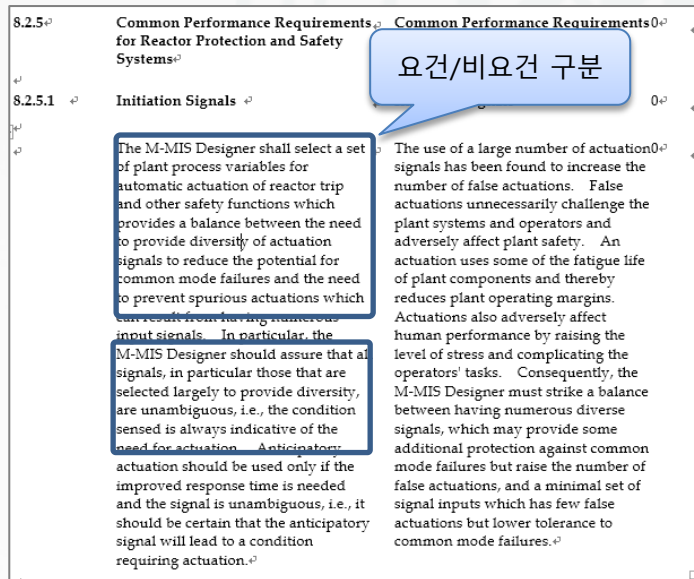


개발된 문서 관리 자동화 체제



개발 절차

- 요건문서 분석
 - 요건문서는 다양한 형태로 저장되거나 관리
 - 문서 유형: 아래 한글, MS-Word, PDF 등
 - 문서 내 Key Word 중심 분석



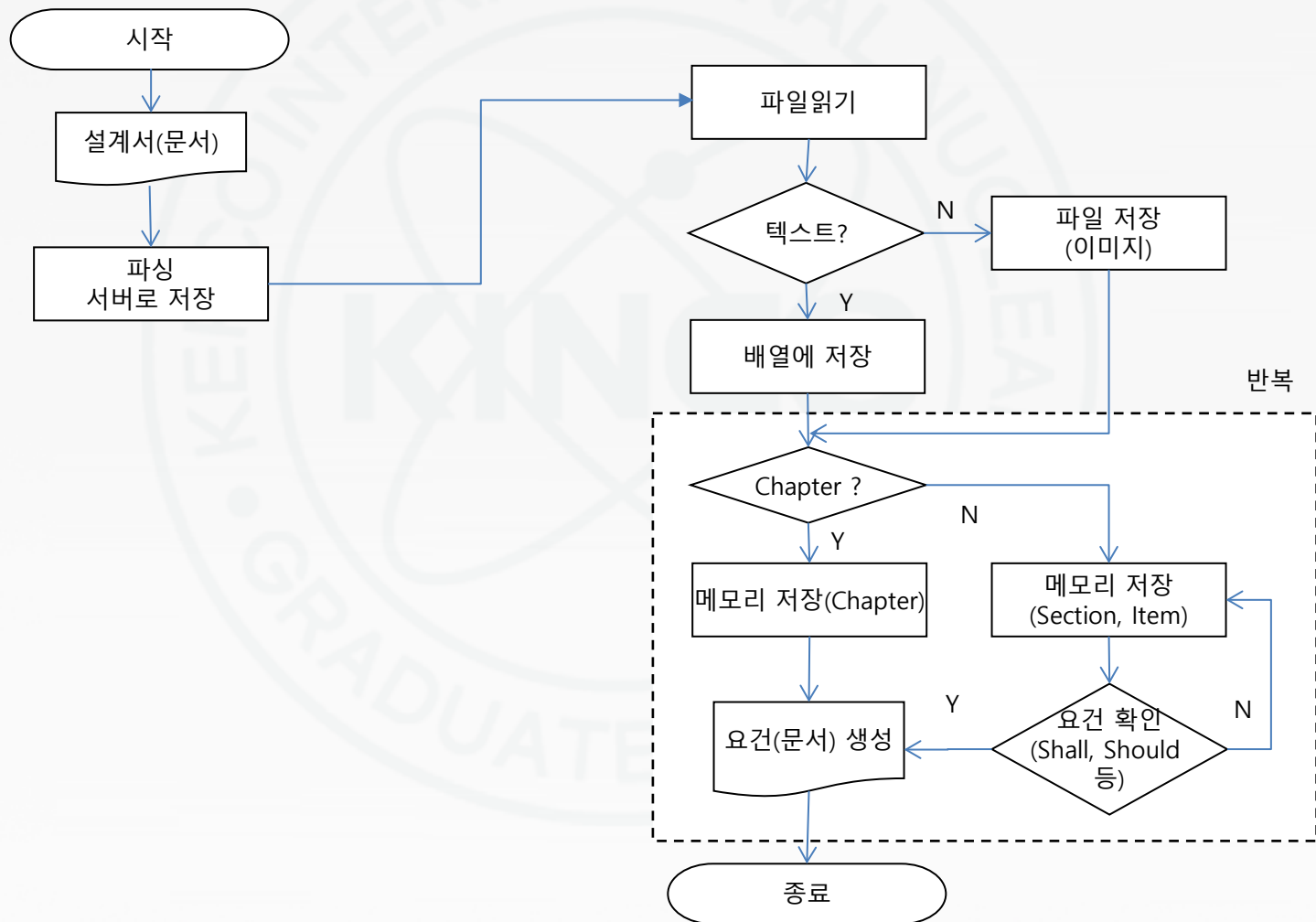
요건/비요건 구분

4	4.1	FUNCTIONS
5	4.1.1	Overview
6	4.1.1.1	The PPS shall include the bistable logic, local coincidence logic, initiation and actuation circuits and other devices necessary to monitor the selected safety-related plant parameters and initiate reactor trip and/or actuation of engineered safety features upon detection of non-permissible plant conditions.
7	4.1.1.2	Initiation of a reactor trip shall be achieved through the RPS and actuation of engineered safety features shall be achieved through the ESFAS.
8	4.1.1.3	Each process parameter monitored by the PPS shall be measured by four redundant instrument channels which are completely separate from plant control channels.
9	4.1.1.4	Each measurement shall be compared to a fixed or variable setpoint.
10	4.1.1.5	If any two or more measurements of a given process parameter exceed the setpoint, the appropriate initiation signals (reactor trip and/or actuation of engineered safety features) shall be automatically generated by a two-out-of-four coincidence logic.
11	4.1.1.6	The two-out-of-four coincidence logic shall be converted to two-out-of-three during maintenance, channel failure, or testing as needed.
12	4.1.1.7	Reactor trip shall be accomplished by interruption of power to the holding coils of the magnetic-jack Control Element Drive Mechanisms (CEDMs) allowing a gravity scram of each Control Element Assembly (CEA).
13	4.1.1.8	Engineered safety features shall be actuated by de-energizing control logic.
14	4.1.1.9	The PPS shall automatically provide alarms and, in some cases, limiting signals to control systems, whenever the selected plant process parameters approach the predetermined levels where plant protection would be required.

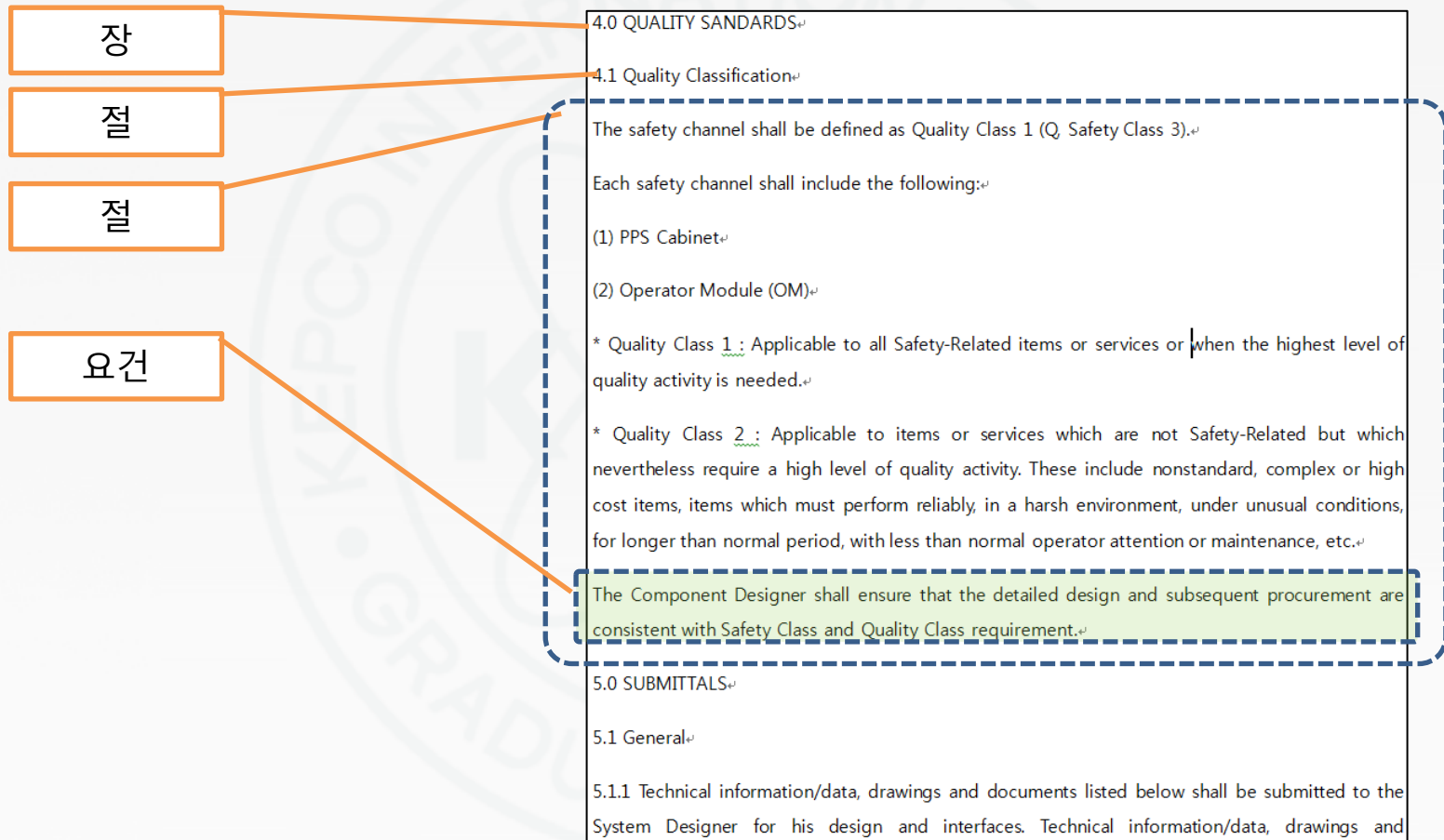
MS-Word, 아래한글, PDF 등

관리 항목으로 분류
(문장 단위로 분리)

문서 파싱 처리 절차



파싱 전 문서

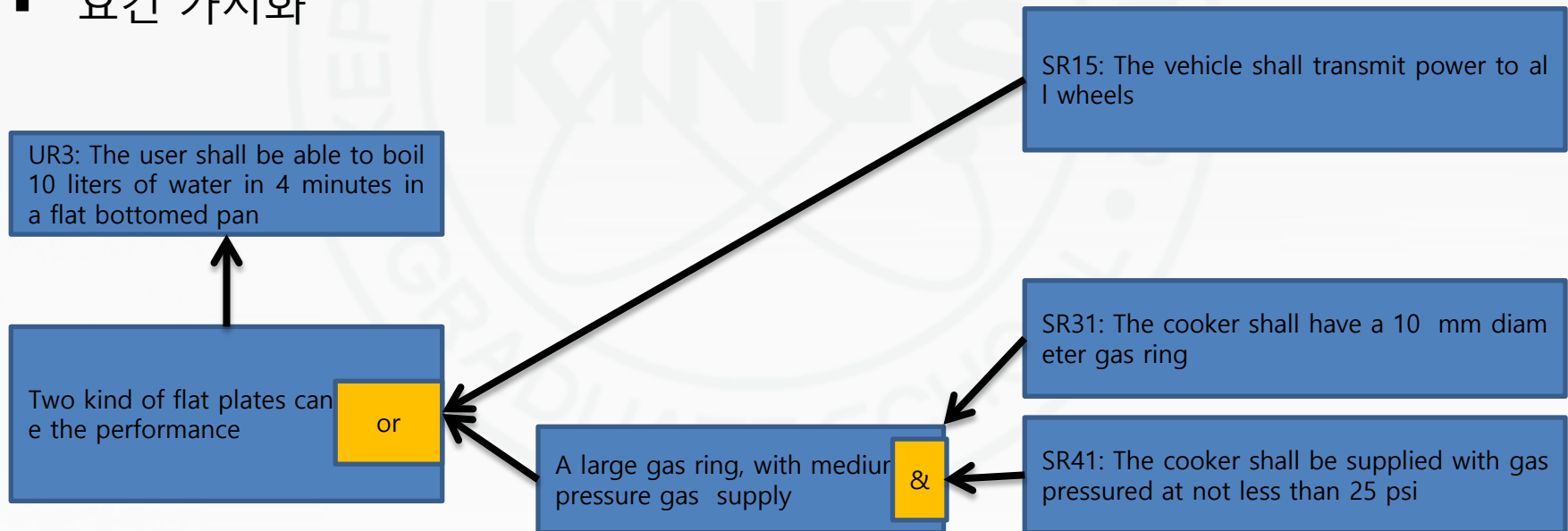


요건 관리 기능

■ 문서 내용 (요건) 추출 :

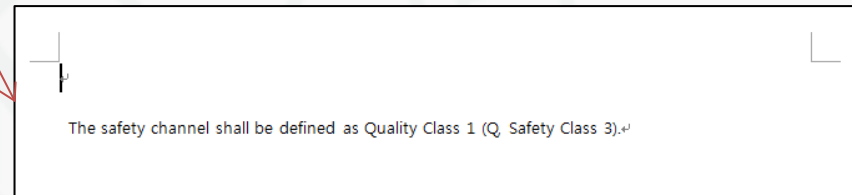
Identifier	Requirements	Quantitative/ Qualitative	Priority	Importance	V&V Method
PR***	* Should describe how well the system should perform its requirements and affect its environment.	Select either one	Key, Mandatory, Operational. Desirable	Scale 0-10	Analysis, Inspection, System test Agreed

■ 요건 가시화



파싱 후 내용 전 문서

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8.2.5 Common Performance Requirements for Reactor Protection and Safety Systems

8.2.5.1 Initiation Signals

The M-MIS Designer shall select a set of plant process variables for automatic actuation of reactor trip and other safety functions which provides a balance between the need to provide diversity of actuation signals to reduce the potential for common mode failures and the need to prevent spurious actuations which can result from having numerous input signals. In particular, the M-MIS Designer should assure that all signals, in particular those that are selected largely to provide diversity, are unambiguous, i.e., the condition sensed is always indicative of the need for actuation. Anticipatory actuation should be used only if the improved response time is needed.

The use of a large number of actuation signals has been found to increase the number of false actuations. False actuations unnecessarily challenge the plant systems and operators and adversely affect plant safety. An actuation uses some of the fatigue life of plant components and thereby reduces plant operating margins. Actuations also adversely affect human performance by raising the level of stress and complicating the operators' tasks. Consequently, the M-MIS Designer must strike a balance between having numerous diverse signals, which may provide some additional protection against common mode failures but raise the number of false actuations, and a minimal set of

요건/비요건 구분

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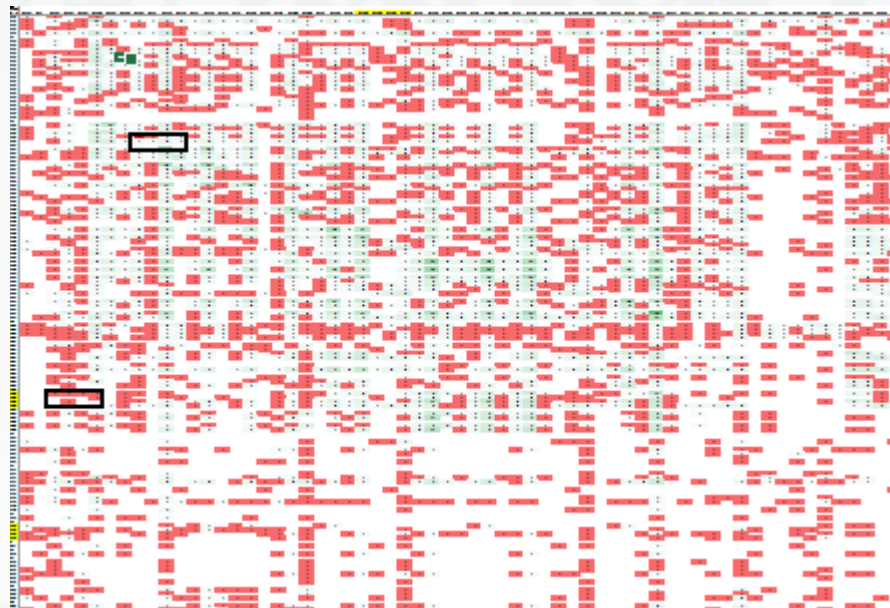
추적성 분석

- 추적성 분석 프로그램
 - 단어 기반 추적성 분석 및 전문가 일치여부 확인
 - 상하위 요건간 가중치 부여 등

상위요건		하위 요건 ID	하위 기능 Description	요건 ID Nuber
4.1	FUNCTIONS	6.0		
5	4.1.1 Overview	6.1		
6	4.1.1.1 The PPS shall include the bistable logic to monitor the selected safety-related plant parameters and initiate reactor trip and/or actuation of engineered safety features upon non-permissible plant conditions.			4.11.1, 4.11.3, 4.11.5, 4.11.9, 4.11.10, 4.12.1, 4.12.4, 4.12.5, 4.12.11, 4.13.5, 4.14.4, 4.15.1, 4.15.7, 4.15.8, 4.15.9, 4.16.1, 4.17.1, 4.17.4, 4.17.2, 4.17.2.4, 4.17.2.8, 4.17.2.10, 4.18.1, 4.19.1, 4.110.1, 4.2, 4.2.2, 4.2.5, 5.0, 5.0.1, 5.1, 5.1.1, 5.11.1, 5.12.1, 5.12.2, 5.12.5, 5.13.1, 5.13.1, 5.13.1, 5.13.1.2, 5.13.2, 5.14.1, 5.14.1.3, 5.14.2, 5.14.2.2, 5.14.2.4, 5.14.2.7, 5.15.1, 5.15.2, 5.16.1, 5.16.5, 5.16.7, 5.16.8, 5.16.9, 5.17, 5.17.1, 5.18, 5.18.1, 5.18.1, 5.18.1, 5.18.2, 5.18.3, 5.19, 5.19.1, 5.110.1, 5.110.2, 5.110.3, 5.110.5, 5.110.7, 5.111, 5.111.1, 5.112, 5.112.1, 5.113, 5.113.1, 5.114, 5.115, 5.115.1, 5.116, 5.116.3, 5.2, 5.21, 5.21.1, 5.22, 5.22.1, 5.23, 5.23.1, 5.23.3, 5.24, 5.24.1, 5.24.4, 5.24.5, 5.24.6, 5.25, 5.3, 5.3.1, 5.3.1.2, 5.3.2, 5.3.2.3, 5.4, 5.4.1, 5.4.2, 5.4.2.2
7	4.1.1.2 Initiation of a reactor trip shall be achieved through the RPS and actuation of engineered safety features shall be achieved through the ESFAS.			4.11.1, 4.11.2, 4.11.3, 4.11.5, 4.11.7, 4.11.8, 4.11.9, 4.11.10, 4.12.1, 4.12.2, 4.12.3, 4.12.4, 4.12.5, 4.12.6, 4.12.7, 4.12.1, 4.12.1.1, 4.12.1.2, 4.12.2, 4.12.2.1, 4.12.2.2, 4.12.3, 4.12.3.1, 4.12.4, 4.12.4.1, 4.12.4.2, 4.12.5, 4.12.5.1, 4.12.6, 4.12.6.1, 4.12.6.3, 4.12.6.4, 4.12.7, 4.12.7.1, 4.12.7.2, 4.12.8, 4.12.8.1, 4.12.9, 4.12.9.1, 4.12.9.4, 4.12.9.5, 4.12.10, 4.12.10.1, 4.12.11, 4.12.11.1, 4.12.12, 4.12.12.1, 4.12.12.2, 4.12.12.3, 4.12.12.4, 4.13.1, 4.13.2, 4.13.3, 4.13.4, 4.13.5, 4.13.1, 4.13.1.1, 4.13.1.2, 4.13.1.3, 4.13.1.4, 4.13.1.5, 4.13.1.6, 4.13.1.7, 4.13.2, 4.13.2.1, 4.13.2.2, 4.13.2.3, 4.13.2.4, 4.13.2.5, 4.13.2.6, 4.13.3, 4.13.3.1, 4.13.3.2, 4.13.3.3, 4.13.3.4, 4.13.4, 4.13.4.1, 4.13.4.2, 4.13.4.3, 4.13.4.4, 4.13.4.5, 4.13.5, 4.13.5.1, 4.13.5.3, 4.13.5.4, 4.14.1, 4.14.4, 4.15.1, 4.15.5, 4.15.5, 4.15.7, 4.15.8, 4.15.9, 4.16.1, 4.16.2, 4.17, 4.17.1, 4.17.2, 4.17.3, 4.17.4, 4.17.1, 4.17.1.1, 4.17.1.2, 4.17.1.3, 4.17.1.4, 4.17.2, 4.17.2.1, 4.17.2.2, 4.17.2.3, 4.17.2.4, 4.17.2.6, 4.17.2.7, 4.17.2.8, 4.17.2.9, 4.17.2.10, 4.17.2.11, 4.17.2.12, 4.17.2.13, 4.17.2.14, 4.17.2.15, 4.18.1, 4.18.1.1, 4.18.2, 4.18.2.1, 4.18.3, 4.19, 4.19.1, 4.19.2, 4.110.1, 4.110.2, 4.2, 5.0, 5.1, 5.11, 5.11.1, 5.12.1, 5.12.2, 5.13, 5.13.1, 5.13.1.1, 5.13.1.2, 5.13.3, 5.14.1, 5.14.1.1, 5.14.1.2, 5.14.1.3, 5.14.1.4, 5.14.1.5, 5.14.1.7, 5.14.1.8, 5.14.2, 5.14.2.2, 5.14.2.5, 5.14.2.6, 5.14.2.7, 5.15.1, 5.15.2, 5.16.1, 5.16.4, 5.16.5, 5.16.6, 5.16.7, 5.16.8, 5.16.9, 5.17.1, 5.17.3, 5.17.4, 5.17.5, 5.18.1, 5.18.1, 5.18.1.1, 5.18.2, 5.18.3, 5.19.1, 5.110.2, 5.110.3, 5.110.4, 5.110.5, 5.110.7, 5.112, 5.113, 5.114, 5.114.1, 5.114.2, 5.115, 5.115.2, 5.116, 5.116.1, 5.116.2, 5.116.3, 5.116.4, 5.21.1, 5.22.1, 5.23, 5.23.1, 5.23.4, 5.24, 5.24.4, 5.24.6, 5.25, 5.3, 5.3.1, 5.3.1.2, 5.3.2, 5.3.2.3, 5.4, 5.4.1, 5.4.2, 5.4.2.2
8	4.1.1.3 Each process parameter monitored by the PPS shall be measured by four redundant instrument channels which are connected to the plant control channels.			
9	4.1.1.4 Each measurement shall be compared to a fixed or variable setpoint.			
10	4.1.1.5 If any two or more measurements of a given process parameter exceed the setpoint, the appropriate initiation signals (reactor trip and/or actuation of engineered safety features) shall be automatically generated by a two-out-of-four coincidence logic.			
11	4.1.1.6 The two-out-of-four coincidence logic shall be converted to two-out-of-three during maintenance, channel failure, or testing as needed.			
12	4.1.1.7 Reactor trip shall be accomplished by interruption of power to the holding coils of the magnetic-jack Control Element Drive Mechanisms (CEDMs) allowing a gravity scram of each Control Element Assembly (CEA).			
13	4.1.1.8 Engineered safety features shall be actuated by de-energizing control logic.			
14	4.1.1.9 The PPS shall automatically provide alarms and, in some cases, limiting signals to control systems, whenever the selected plant process parameters approach the predetermined levels where plant protection would be required.			
		6.1.1.2	The PPS shall generate signals to actuate Reactor Trip RT and Engineered Safety Features ESF automatically whenever monitored processes reach predefined limits. The PPS shall provide status outputs for operator monitoring and provide manually entered inputs for limited operator intervention of the automatic RT and ESF actuation such as inserting an operating bypass.	

전산화된 문서분석 결과 가시화

Req.	요건 ID					일치 그래프	
Sepec.	4.1.1_10	4.1.2	4.1.2_1	4.1.2_2	4.1.2_3	4.1.2_4	4.1.2_5
DS ID							
6.11_1	2		1			1	
6.11_2	1		3	2	1	10	6
6.11_3	1			1	1	2	1
6.11_4			1	1			
6.11_5			3	2		7	3
6.12							
6.12_1	1		2		1	2	1
6.12_2	1		2		1	5	1



조사 내용 및 방법 : MMIS Event DB 대상

● 내용 및 범위 :

- 조사 기간 : 2000년 ~ 현재
- 조사 대상 :
 - INPO, WANO 회원 원전을 대상 분석한 PWR 관련 사건 143건
 - KINS OPIS 통계 중 MMIS 유발 사건 기록 27건
 - NRC 발표 PWR LER (Licensee Event Report) 중 계측 제어 시스템에 의해 발생한 MMIS 유발, 원전 사건 118건

● 조사 방법

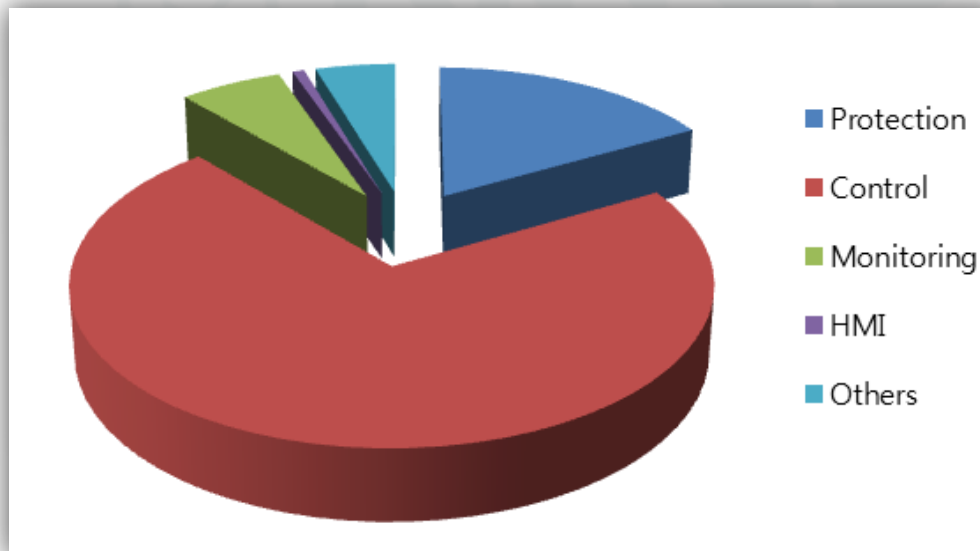
- 고장 원인 및 영향 분석 (FMEA) DB 작성
- 고장 조치 사항 및 재발 방지책에 대한 추가적인 분석 실시
- 정밀 분석 대상 선정 및 추가 분석 예정 : 본 회의 이후

조사 및 분석 내용 : MMIS Event DB 대상

- **MMIS 시스템 분류**

- 계통 분류표를 기준으로 사건 식별
- 노형 및 발전소 설계개념에 따라 다소 상이한 분석이 가능
- 계통 설계 개념이 상이할 경우 최대한 근접 분석 실시

- **사건 유발 시스템 분류 결과**



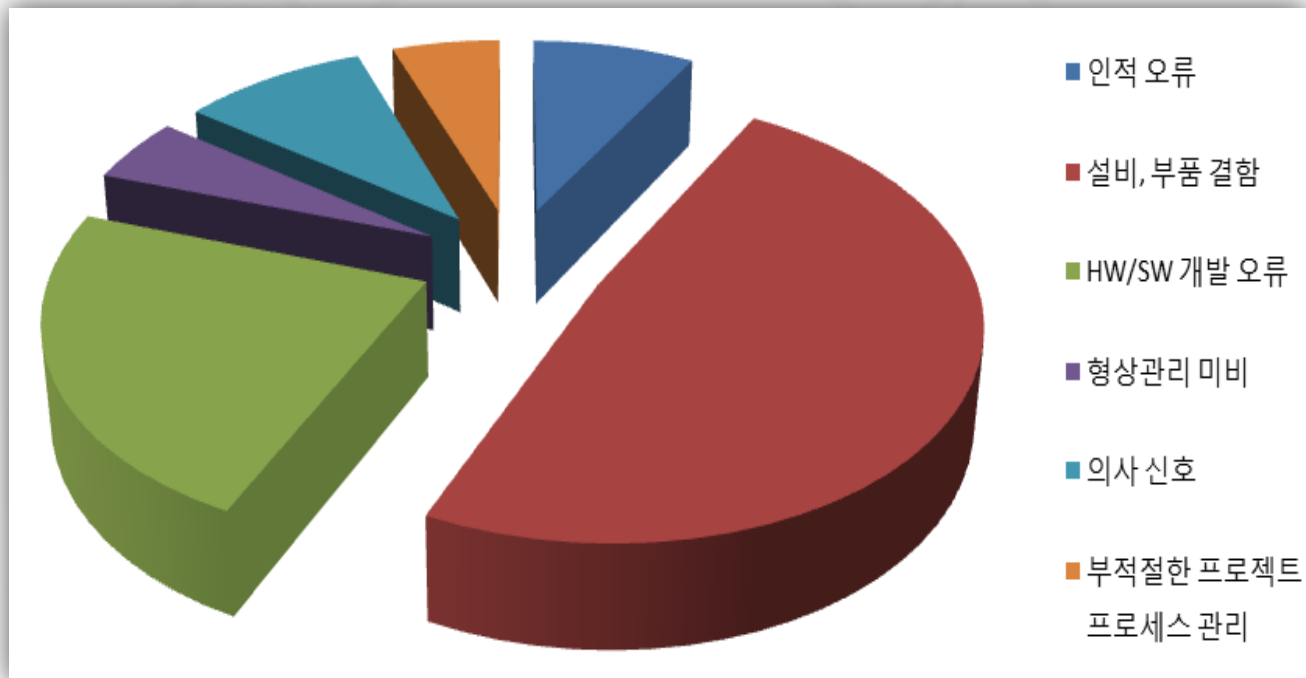
상세 분석 결과

● MMIS 카테고리 별 발생 비율

MMIS Category	Systems	Cases	Cause Rate (%)	Equipment	
Protection System	PPS	9	6.0		
	ESF-CCS	3	2.0		
	RCOPS	13	8.7		
	DPS	2	1.3		
Control System	PCS	33	22.0	DRCS	24
				RRS	7
				RPCS	2
	NPCS	31	20.7	PPCS	2
				SBCS	2
				FWCS	27
	P-CCS	13	8.7		
	TCS	27	18.0		
	EDG	2	1.3		
Monitoring and Human Machine Interface System	ENFMS	8	5.3		
	FIDAS	1	0.7		
	MCR	1	0.7		
Others	Process-RMS	2	1.3		
	CVCS	4	2.7		
	MG-Set	1	0.7		
		150	100%		

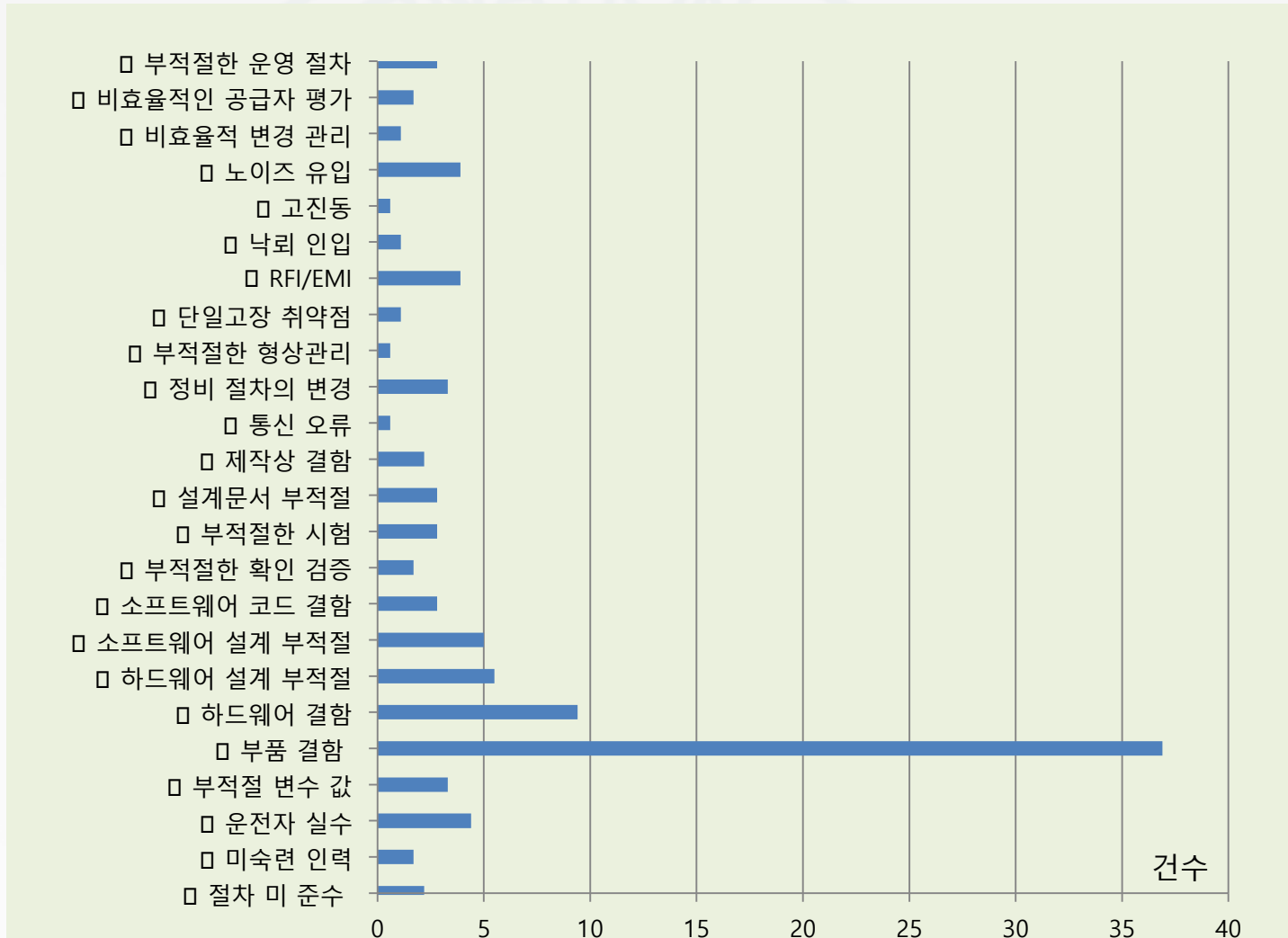
조사 및 분석 결과

- 사건 유발 원인 별 분석 결과



조사 및 분석 결과

● 고장 원인 상세분석 결과



조사 및 분석 결과

● FMEA 활용 개선점

- 개선점 1 : **Event Phase Category** (이벤트의 발생 단계별) 분석 요구
- 개선점 2 : **HW** 및 **SE** 고장률 유형의 정합성 확보를 위한 플랜트의 상세 정보 제공
- 개선점 3 : **DB** 분석 결과와 개선 및 권고사항간의 연결고리 추가

General				Event Date and Title		Event Characteristics (Equivalent)				
DHI Control No.	Plant Information	Docket No	Commercial Operation	Events Date	Event Title	MMIS Category	system	subsystem	component	Safety Class

Event Analysis										
Event Phase Category	Event Occurrence	Event Cause	Detailed Cause		Effect		Corrective action	Equipment Replaced	Action to Prevent Recurrence	
			Category	Summary	Category	Summary			Category	Summary

General				Event Date and Title		Event Characteristics (Equivalent)				Event Analysis											
DHI Control No.	Plant Information	Docket No	Commercial Operation	Events Date	Event Title	MMIS Category	system	subsystem	component	Safety Class	Event Phase Category	Event Occurrence	Event Cause	Detailed Cause		Effect		Corrective action	Equipment Replaced	Action to Prevent Recurrence	
														Category	Summary	Category	Summary			Category	Summary
INPO, WANO DB 자료 분석 결과 (OE : INPO Operation Experience, WER : WANO Event Report, MER : Miscellaneous Event Report)																					
141	ARKANSAS NUCLEAR UNIT 2 (ECN 02050901)	09/01/1978 (20050901)	2005-09-08	Multiple CEDMCS (Control Element Drive Mechanism Control System) Failures Result in Inability to Reposition CEAs (Control Element Assemblies) (Arkansas Nuclear Center)	Control system	DRCS	CEA	CEA			NA	Startup	정확한 시간 관리 및 ACTM 카드 "Hall Effect" 센서 고장	Component defect	The root cause of the missing phase and/or continuous firing phase for CEA 56, CEA 26, and CEA 27 was the failure of optical isolator card components due to age related degradation and heat generated on the board.	others	Multiple CEDMCS failures resulted in the inability to reposition CEAs and this delayed the return to full power operation	Replacement	Optical Isolator Card	Procedure revision	The CEDMCS PM task will be revised to verify fans above upper power switch assemblies are functional on a periodic basis.

원자력 산업의 O&M을 위한 인공지능

- 원자력 분야의 O&M 지원화 분야에 머신 러닝과 빅데이터를 결합한 지원 시스템 구축 필요
 - 머신 러닝 엔진을 DB 구축의 자동화
 - Freeware 도구를 이용한 시험 운영
 - 예측 모델로는 배치 예측 방법을 사용
- 2018년 하반기 과제로 발굴함이 바람직
- 산학연의 공동 R&D 를 통해 원자력 산업체를 지원할 수 있는 방법론 개발이 가능할 것임.
- 4차 산업혁명 기술의 원자력 분야 적용에 대한 지속적 연구가 필요함.