engineering laboratory

Framework for an intelligent knowledge-based manufacturing diagnosis system

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NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Maintenance Diagnosis Framework

Goals

- Create a manufacturing knowledge-based system for diagnostics
- Learn from previous maintenance issues to make better/more efficient decisions
- Formalize root cause analysis procedures for maintenance issues

Maintenance Diagnosis Framework

Motivation

- More accurate predictions of root cause analysis
- Shorter time to investigate problems
  - Less down time
    - Increase Overall Equipment Effectiveness
- Only 14% of respondents of MESA survey claimed they had a corporate analytics program
- Proactive maintenance leads to:
  - Improved uptime
  - Increased longevity
- Cleaner/standardized data makes it easier to integrate new systems for analytics

Maintenance Diagnosis Framework

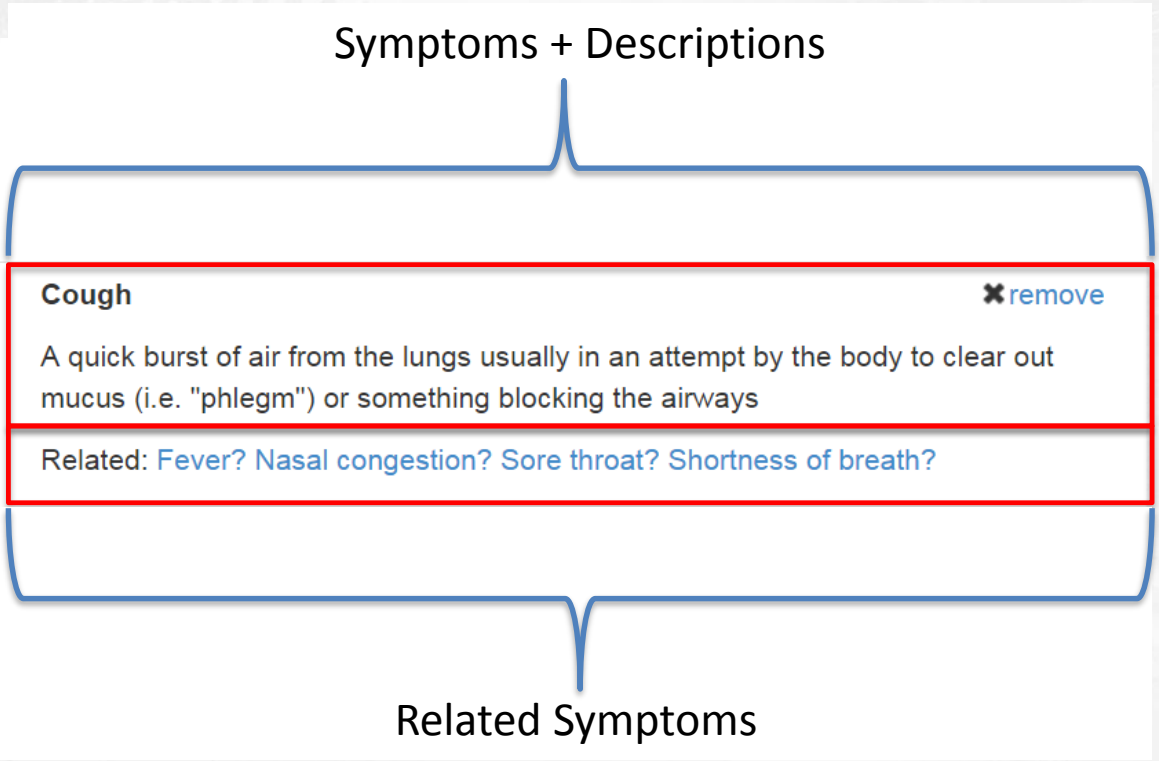
Barriers

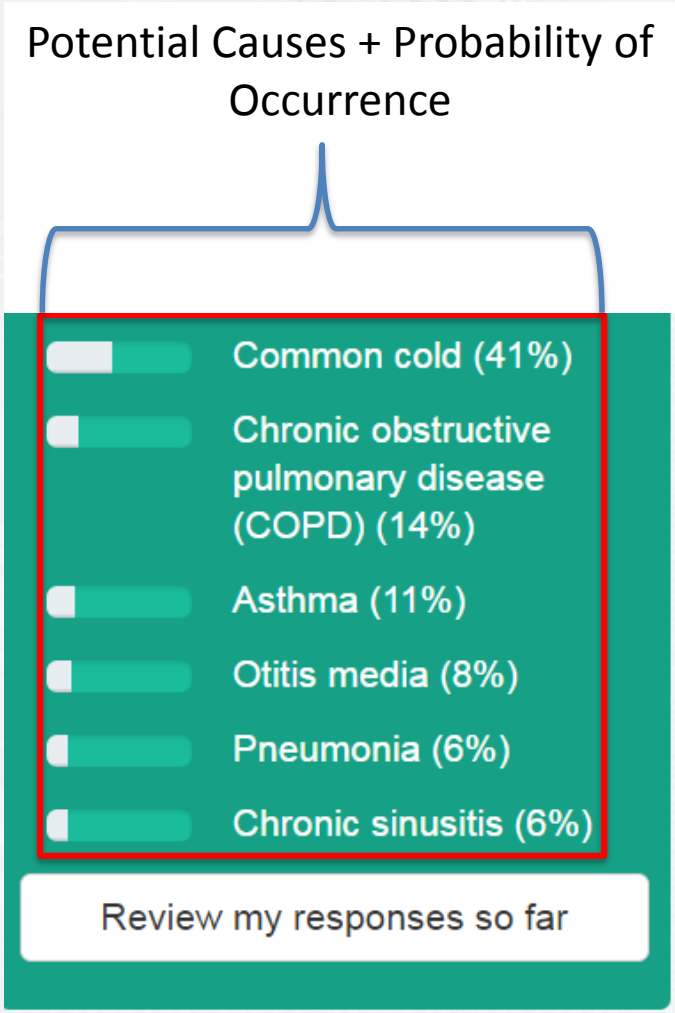
- No standard representation of artifacts for root cause analysis
- Terminology is not standardized
- Root-Cause Analysis is Ad hoc
- Difficult to share information across industries, factories, lines, and employees

Lessons from the Medical Community

- More standardized diagnosis
  - Standardized paths from symptom -> treatment
  - Standardized descriptions of symptoms
- Ontologies for symptom -> diagnosis -> treatment
- Humans are more similar to each other than machines
- Large amounts of available data
- Electronic Health Records (EHR) are required in medical community

Symcat

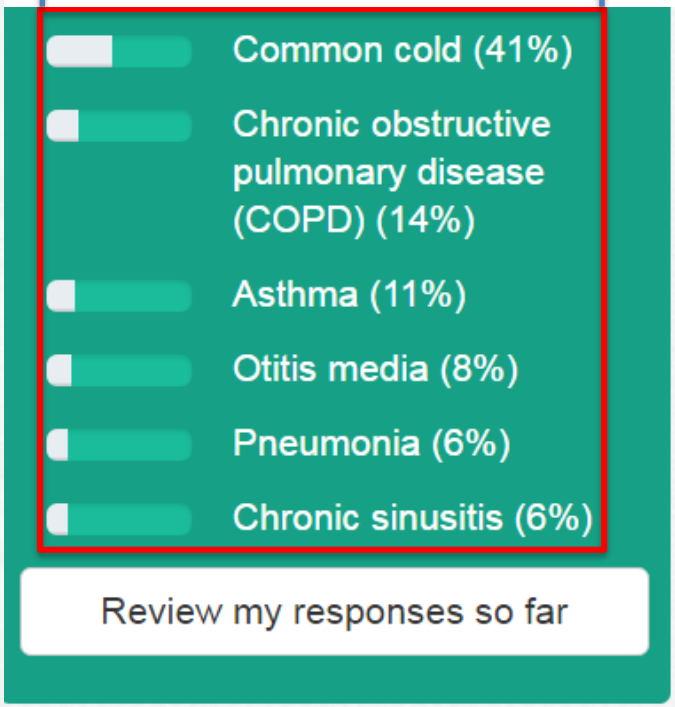




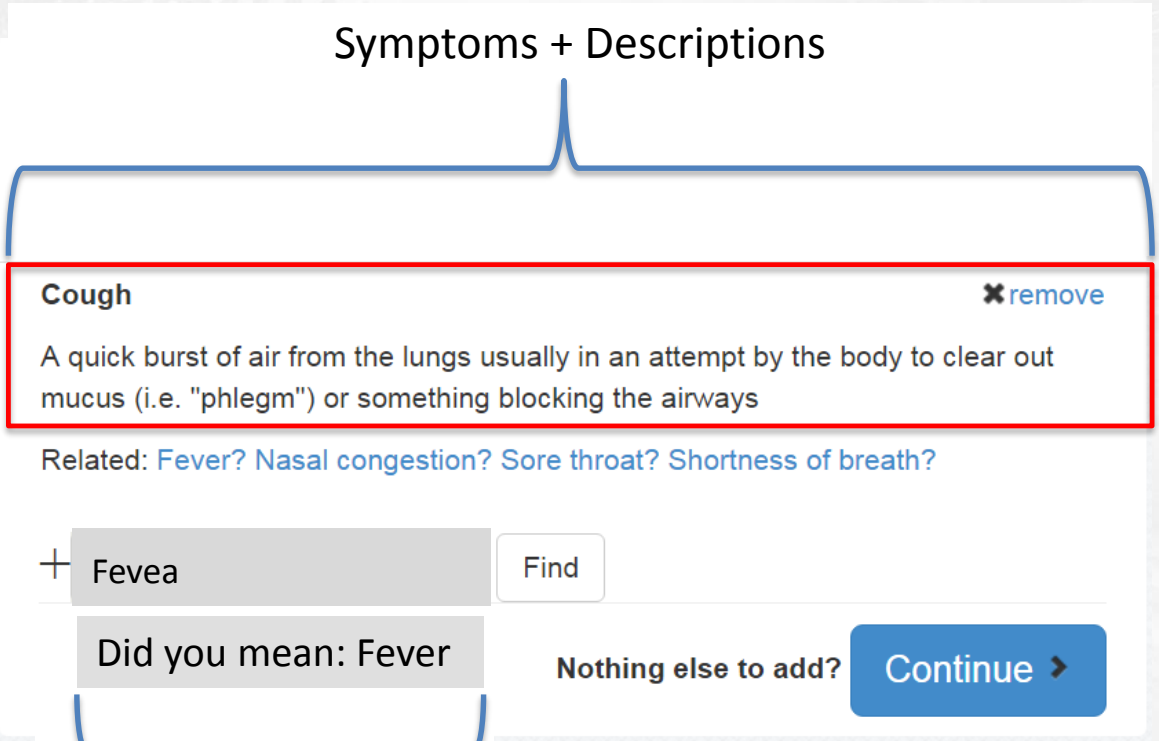
- http://www.symcat.com/

Symcat

Potential Causes + Probability of Occurrence



Symptoms + Descriptions



Natural Language Input + Auto Correct

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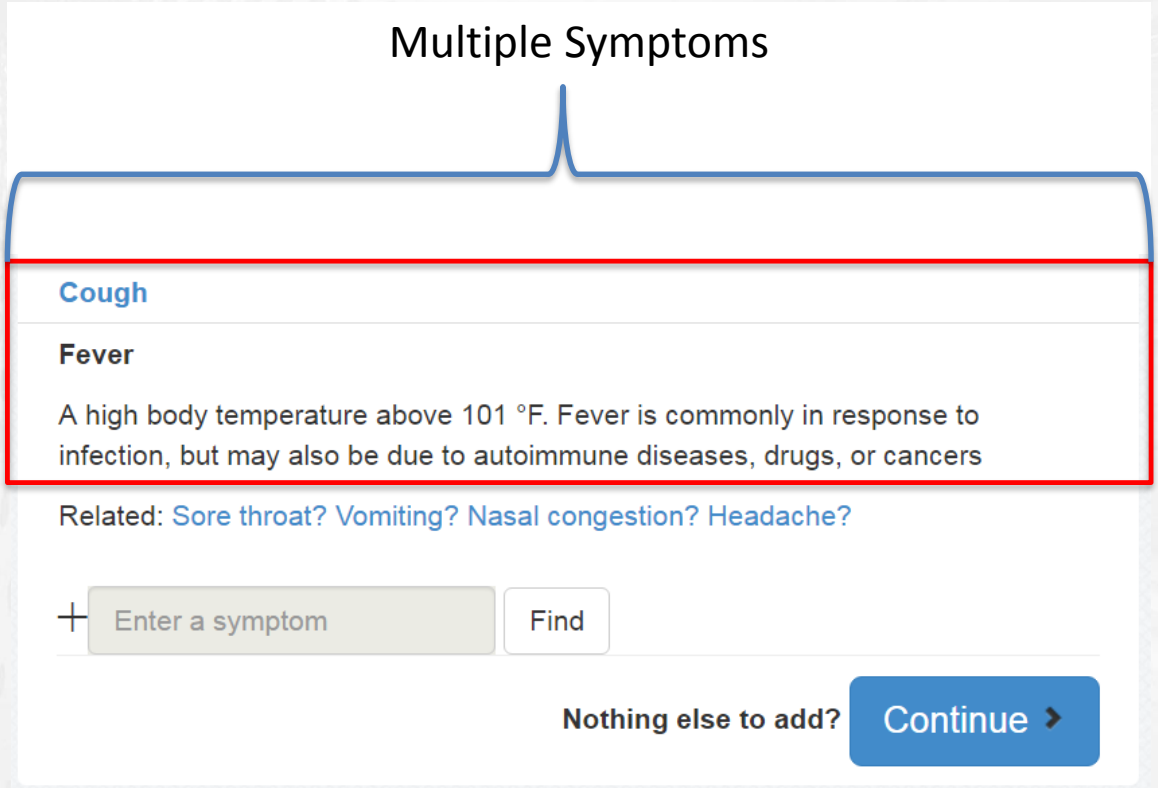
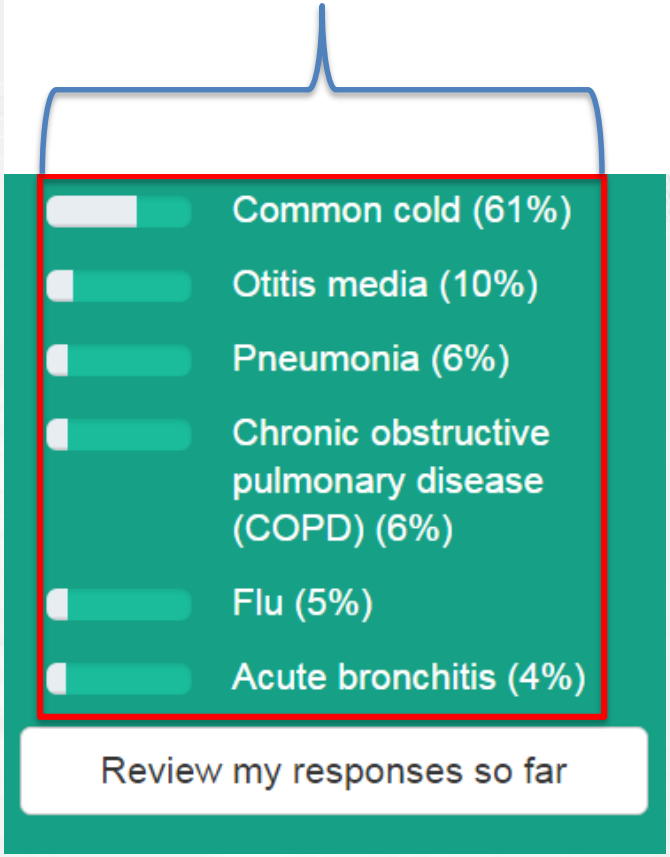
Multiple Symptoms



Updated Probabilities



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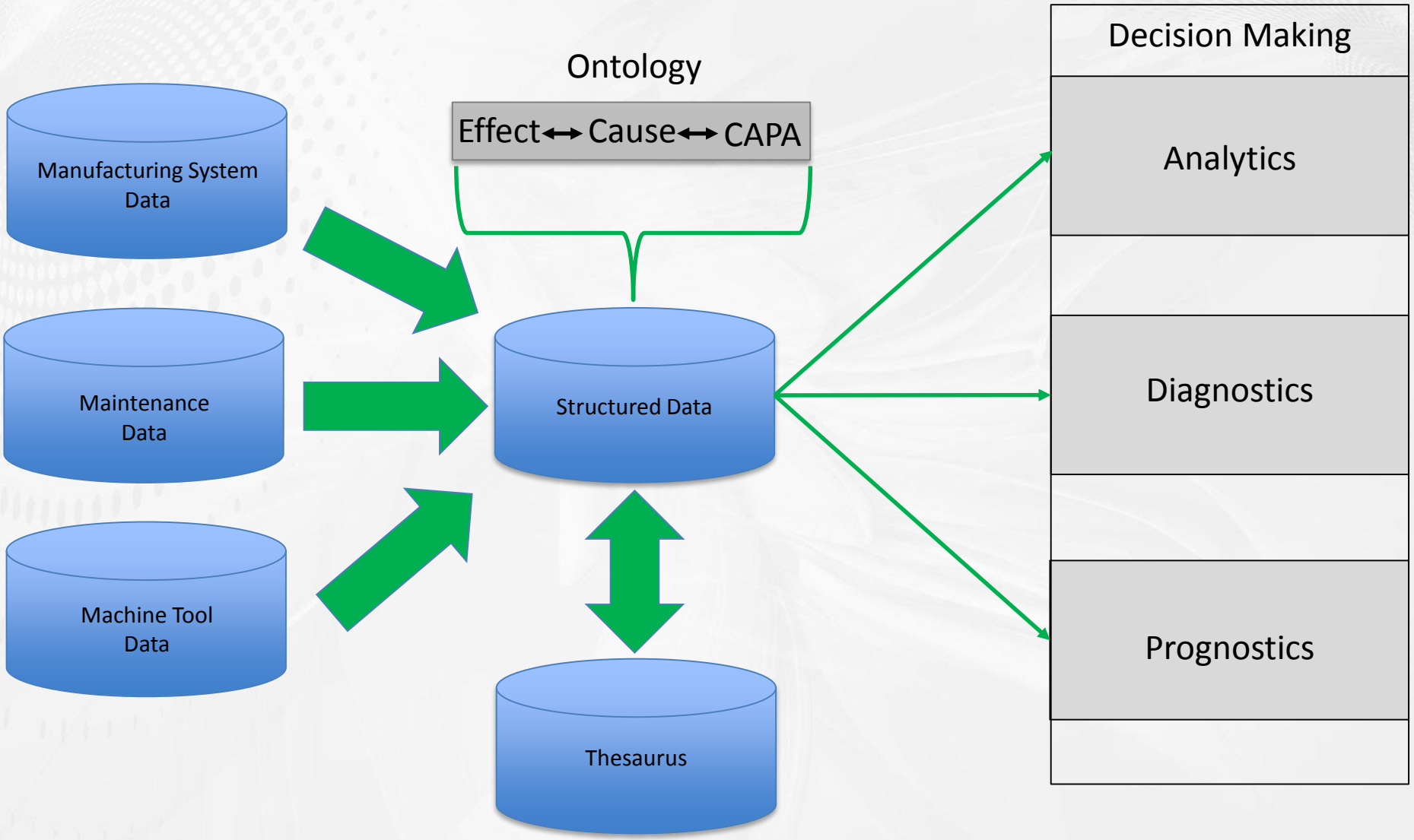
Medical -> Manufacturing

- Research challenges for leaping from medical ->manufacturing
  - Manufacturing Ontologies
  - Data inconsistencies
    - Finding what is the symptom and what is the resolution
  - Not a lot of data
  - Propriety information
  - Tribal knowledge
  - Human illnesses are very similar
    - No ground truth to manufacturing
    - No standardized terms in manufacturing
  - No mandate like HER in manufacturing
    - Need to be ready for digitalization

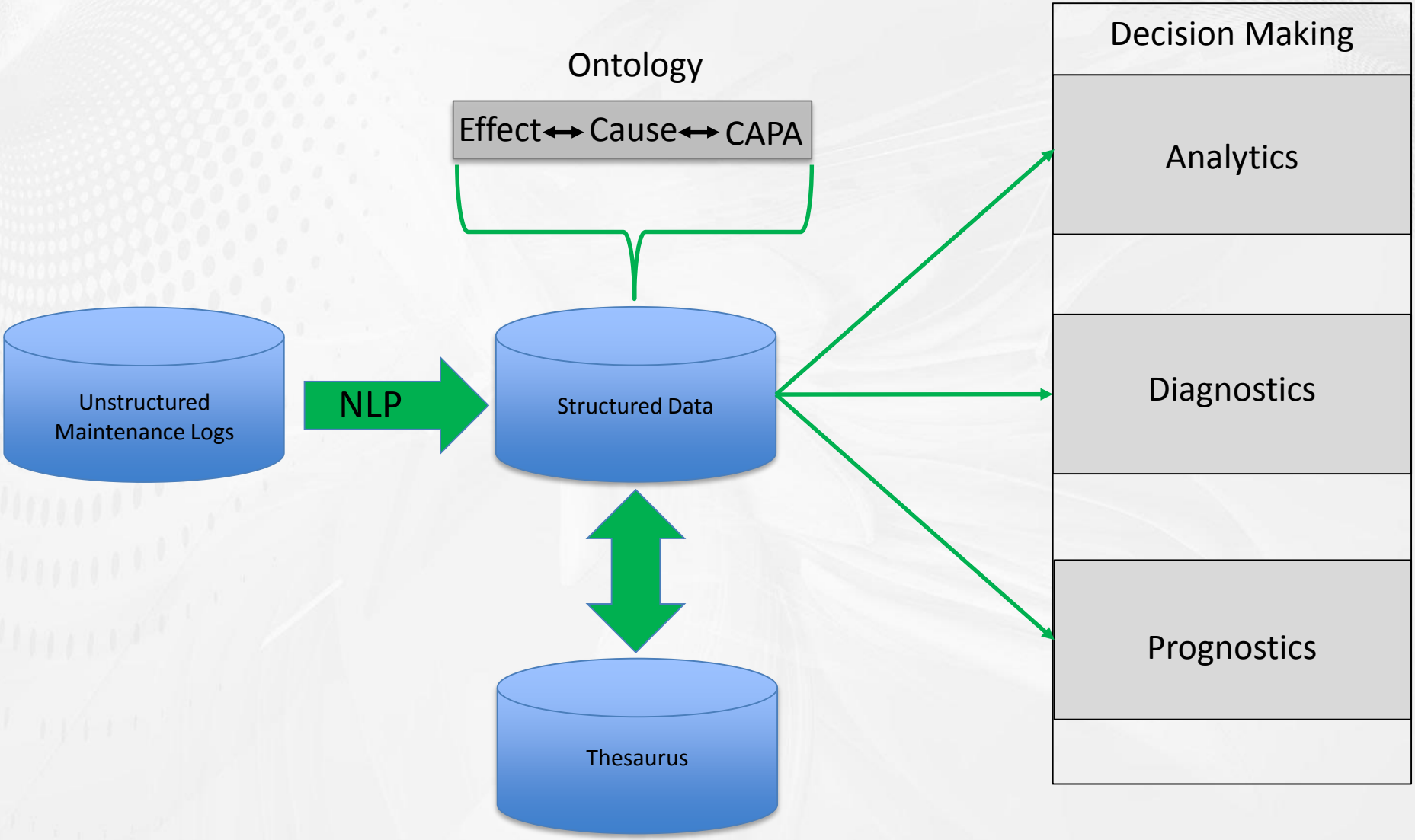
Framework

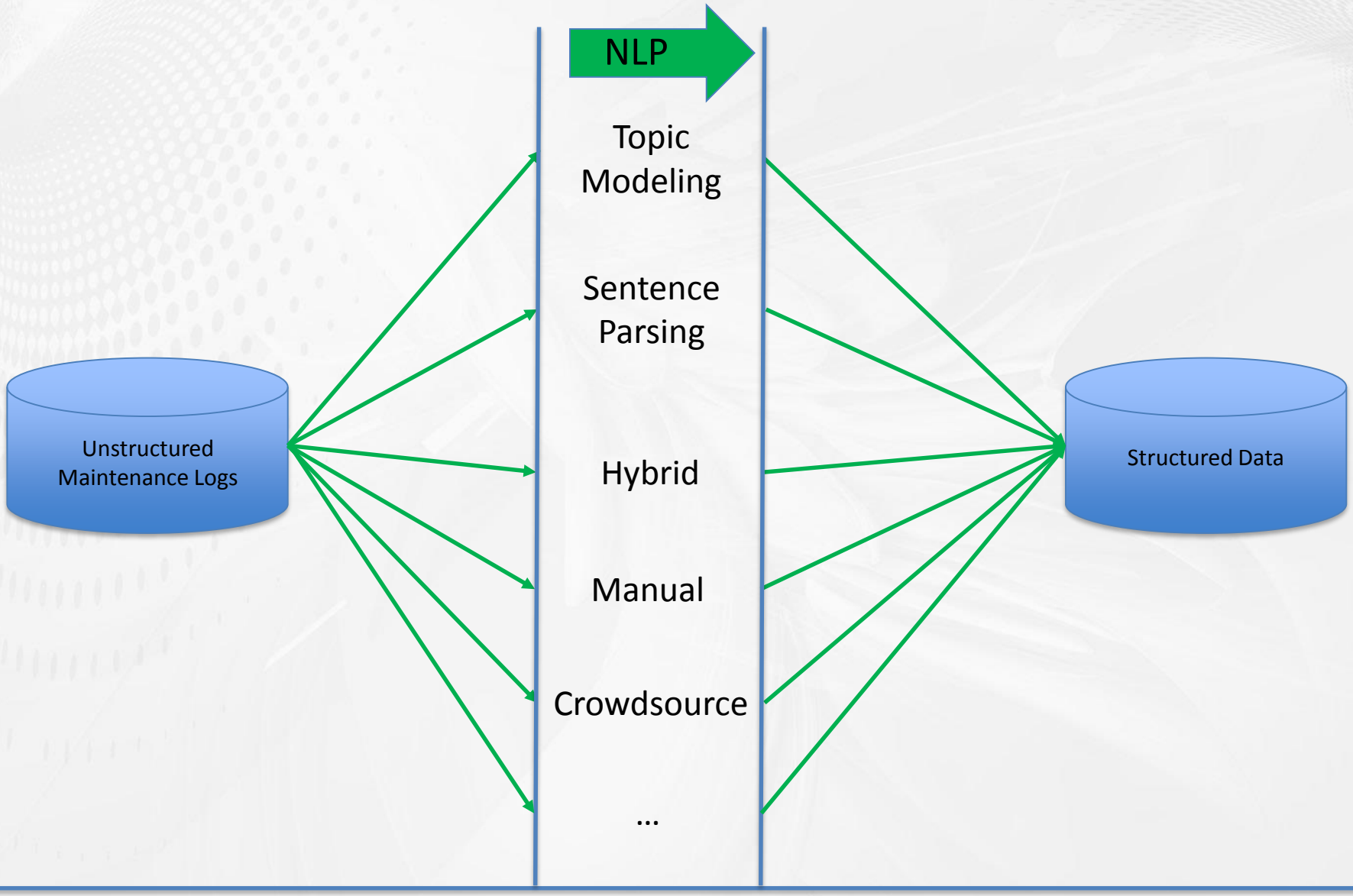

Ontology
Effect ↔ Cause ↔ CAPA
Manufacturing System Data
Maintenance Data
Machine Tool Data
Structured Data
Thesaurus
Decision Making
Analytics
Diagnostics
Prognostics

Data

- Maintenance Data
  - Maintenance logs
  - Maintenance manuals
- Manufacturing Systems
  - MES
  - ERP
  - Control Charts
- Machine Tool Data
  - MTConnect

Initial Framework



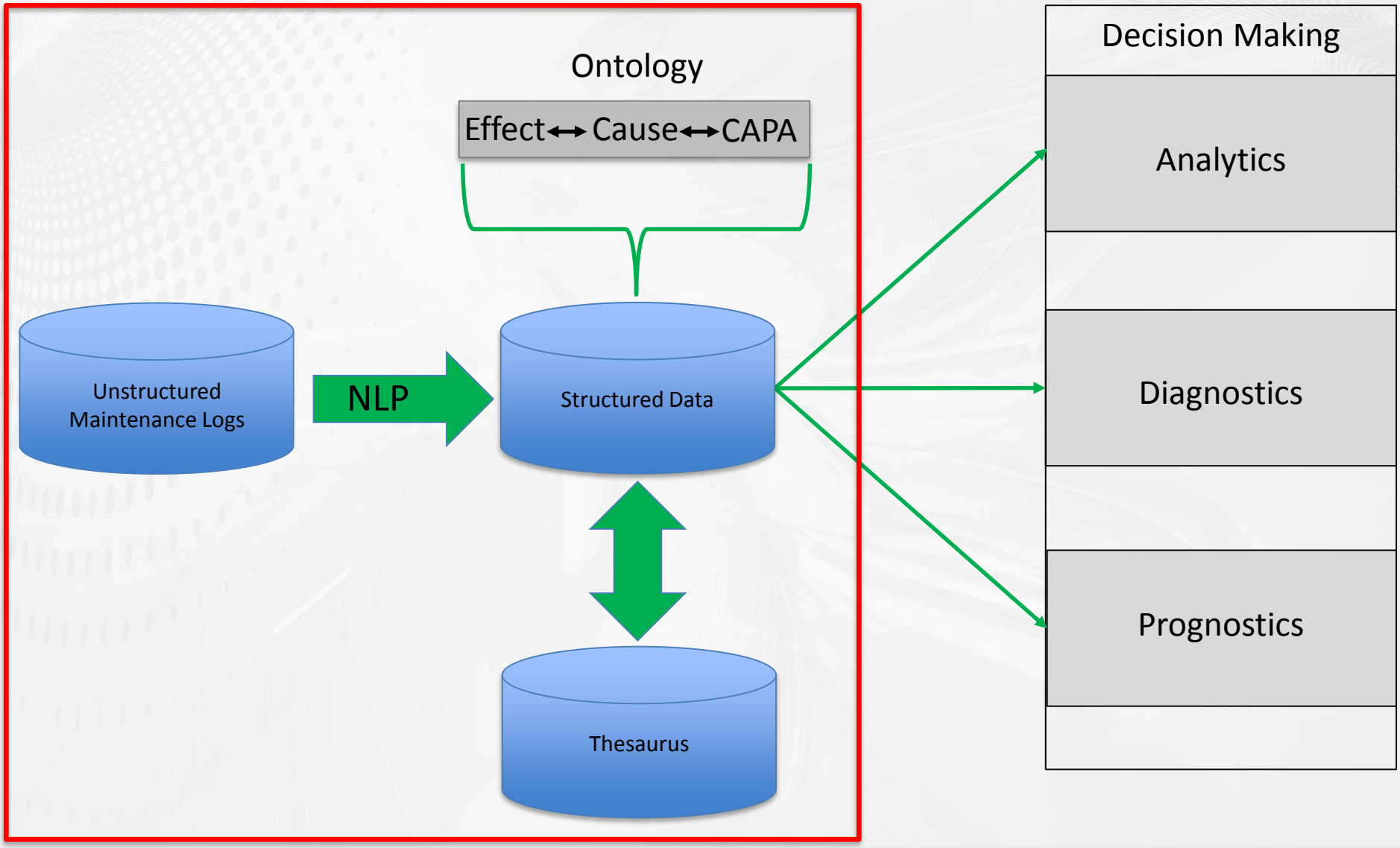

NLP
Topic Modeling
Sentence Parsing
Hybrid
Manual
Crowdsource
…
Unstructured Maintenance Logs
Structured Data

NLP vs. manual tagging

Manual	Hybrid	NLP
No rules, no drop downs	Rules, autocomplete	Bag of words/ Levenshtein distance
Rules, no drop down	Crowdsourcing – rules, autocomplete	Tensor Flow: word2vec/ Bag of words
Rules, drop down	Dictionary for common concepts (NLP -> manual)	Latent Dirichlet allocation (LDA)
Crowdsourcing, rules, no drop downs	Crowdsourcing - dictionary for common concepts	Topic Modeling
Crowdsourcing, rules, drop down	NLP Learns from user cleaned subset of data	

Example of rules:

- Effect(s): Noun Verb (ex. Hyrdaulic Leak)
- Cause(s): Adjective Noun (ex. Missing Fitting)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Description	Resolution
Replace Battery Fault	Replaced Battery
Power Supply Alarm	X Axis Over travelled limit switch
Chip Conveyor Jam	Cleared by hand crank
Chip Conveyor INOP	Cleared large nest of chips
Side A Turret Has Chips	Removed and cleaned
Hydraulic Leak	Replaced ruptured hydraulic leak side B
Exit Conveyor Jam	Replaced broken section of belt
Chip Conveyor Jammed	Hand cranked to free minor jam
Side B Hydraulic leak	Hydraulic return line replaced
Side A Turret Will Not Lock	Fixed
Side A Turret Leaking Coolant	Broken Coolant Line Fixed
Chips in Side A Turret	Turret removed, cleaned, reinstalled, and aligned
Conveyor Jam	Hand cranked to free minor jam
Drive Faults	Replaced LT module on Spindle #3
Hydraulic Leak	Replaced hydraulic hose/base drained with new coolant
Hydraulic Faults	P/P Will not build pressure
Side B Turret Won’t Lock	Spindle Collision with Turret
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Description
Chip Conveyor Jam
Chip Conveyor INOP
Exit Conveyor Jam
Chip Conveyor Jammed
Conveyor Jam
Chip Conveyor Jammed

	Instance
Higher Level Concept	Conveyor INOP
Preferred Label	Chip Conveyor Jammed
Alternative Label(s)	Chip Conveyor Jam, Conveyor Jam, Chip Conveyor INOP
Description	The chip conveyor has chips jammed, which renders the machine inoperable until the chips are cleared

	Instance
Higher Level Concept	Conveyor INOP
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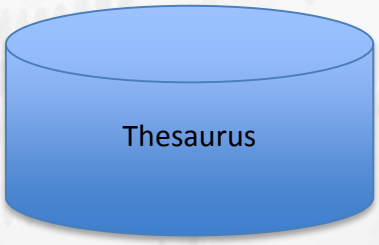

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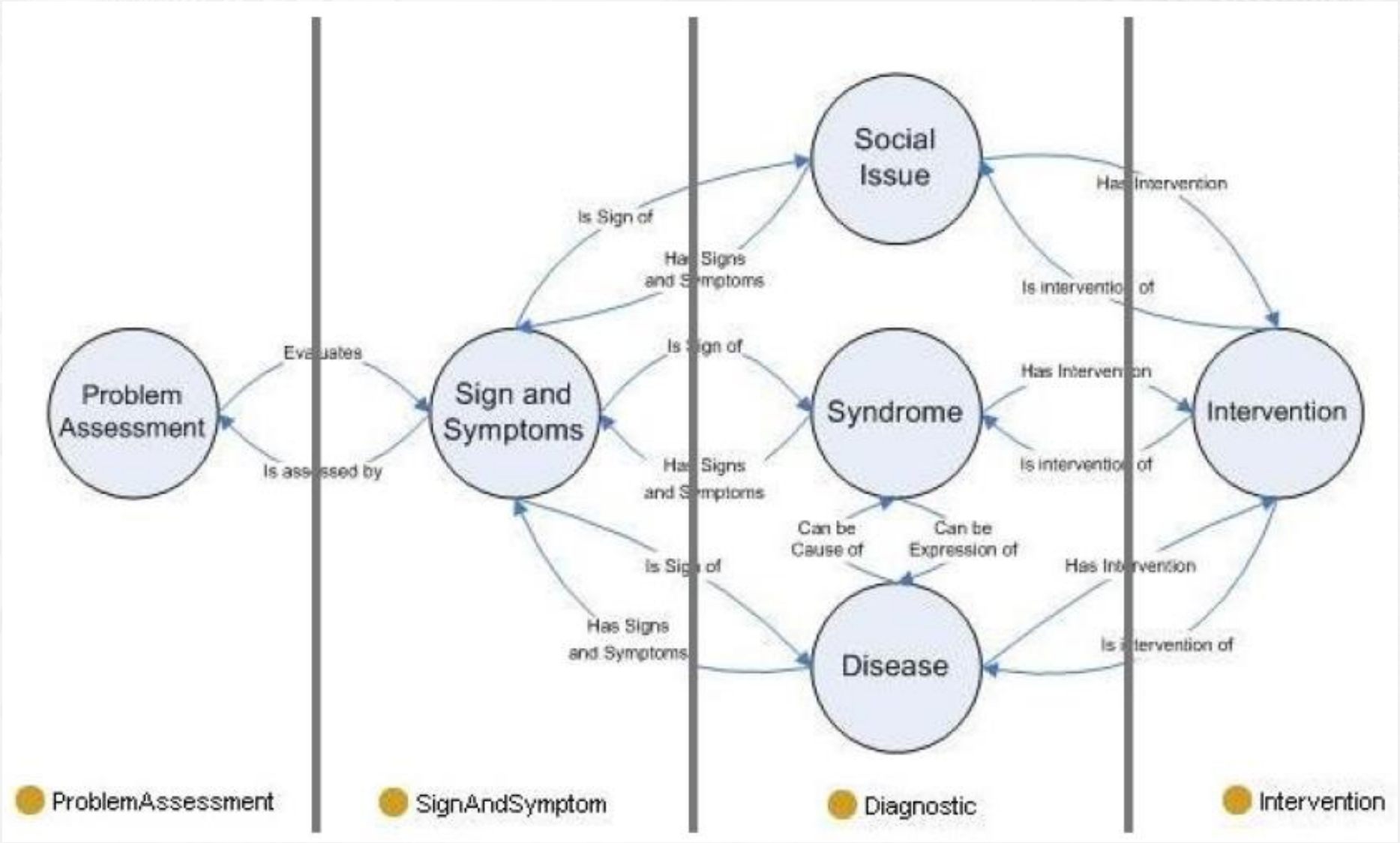
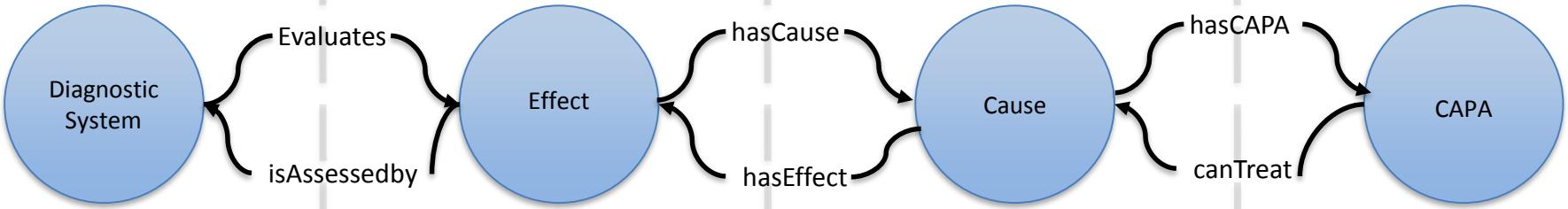
Lessons from the Medical Community



Riano D., et al., C. An ontology-based personalization of health-care knowledge to support clinical decisions for chronically ill patients. Journal of Biomedical Informatics. June 2012, 45(3), 429-446.

Initial Manufacturing Diagnosis Ontology



ProblemAssessment

ObservedEffects

Diagnostic

Treatment

Description

Hydraulic Leak at cutoff unit

Resolution

Missing fitting replaced

Hydraulic Leak

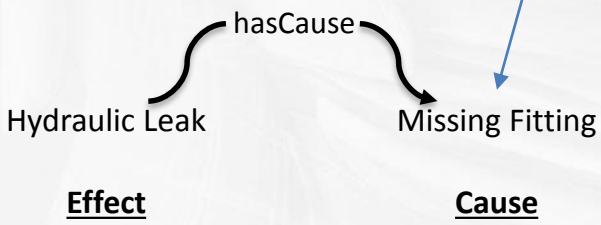
Effect

Description

Hydraulic Leak at cutoff unit

Resolution

Missing fitting replaced



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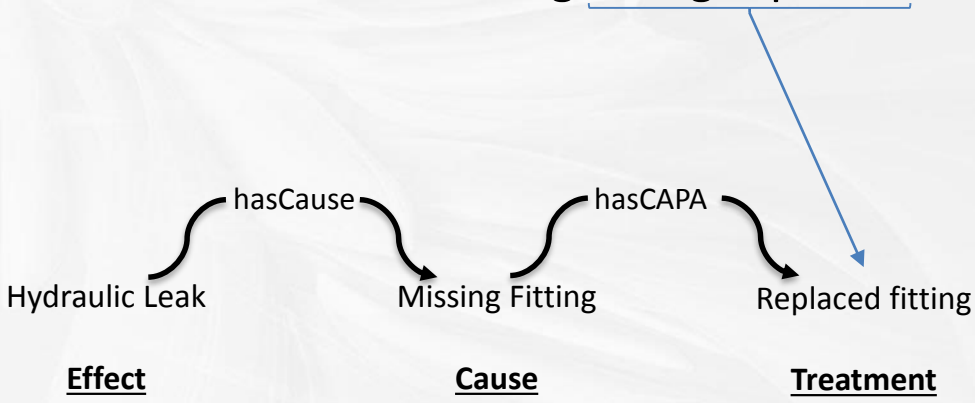

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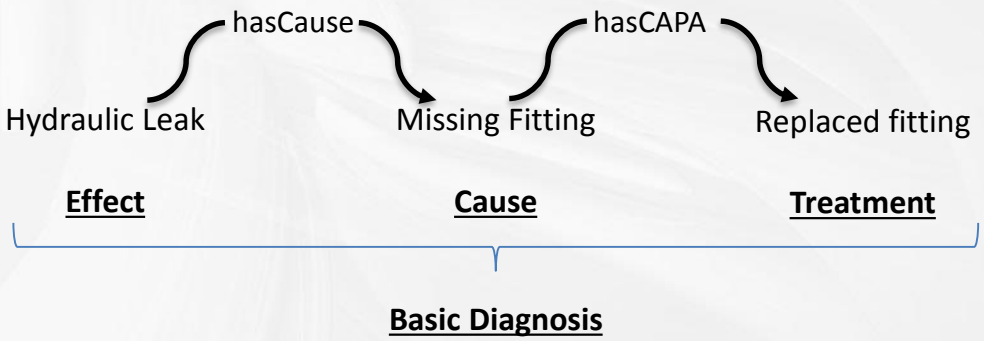

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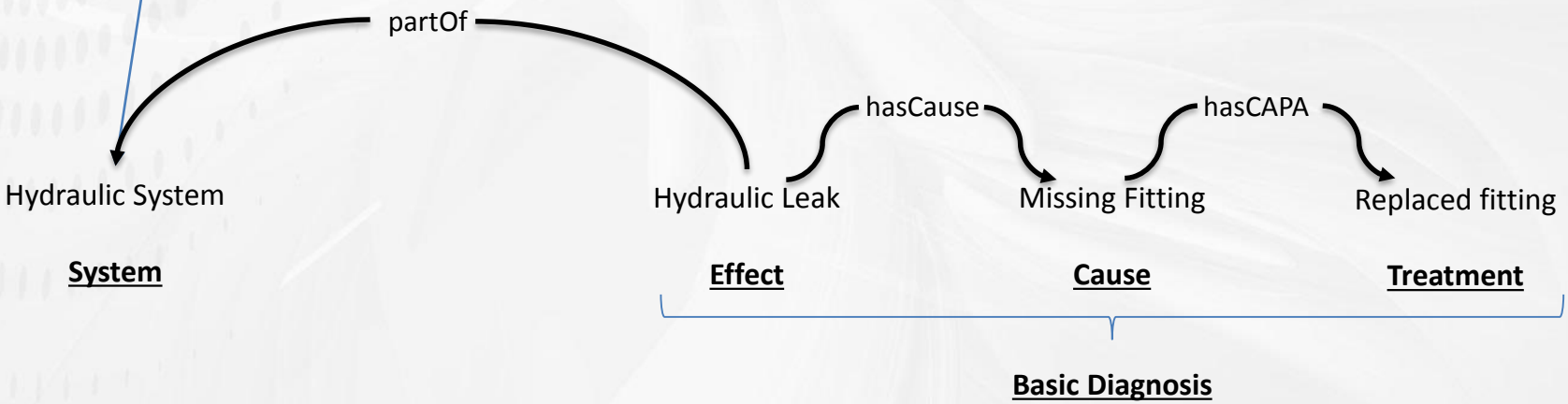

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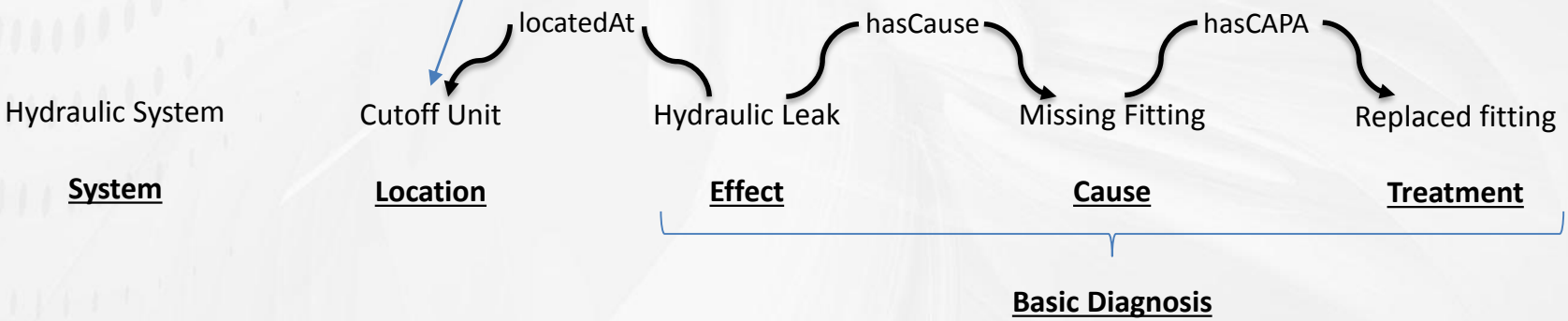

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Resolution

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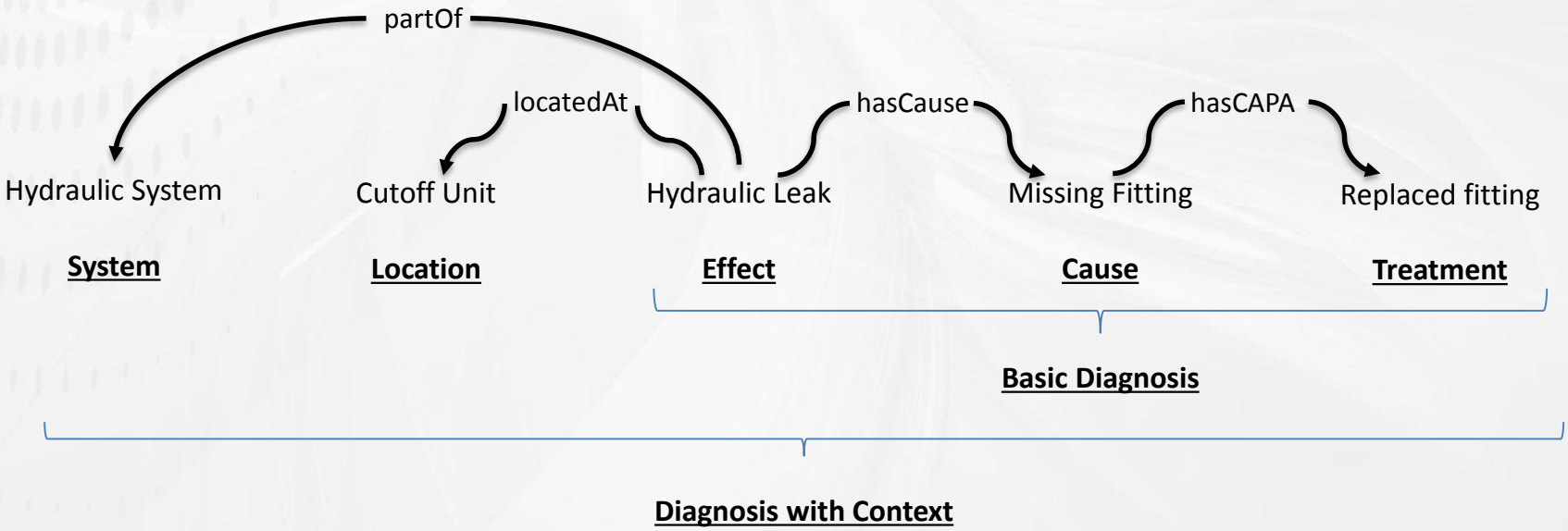
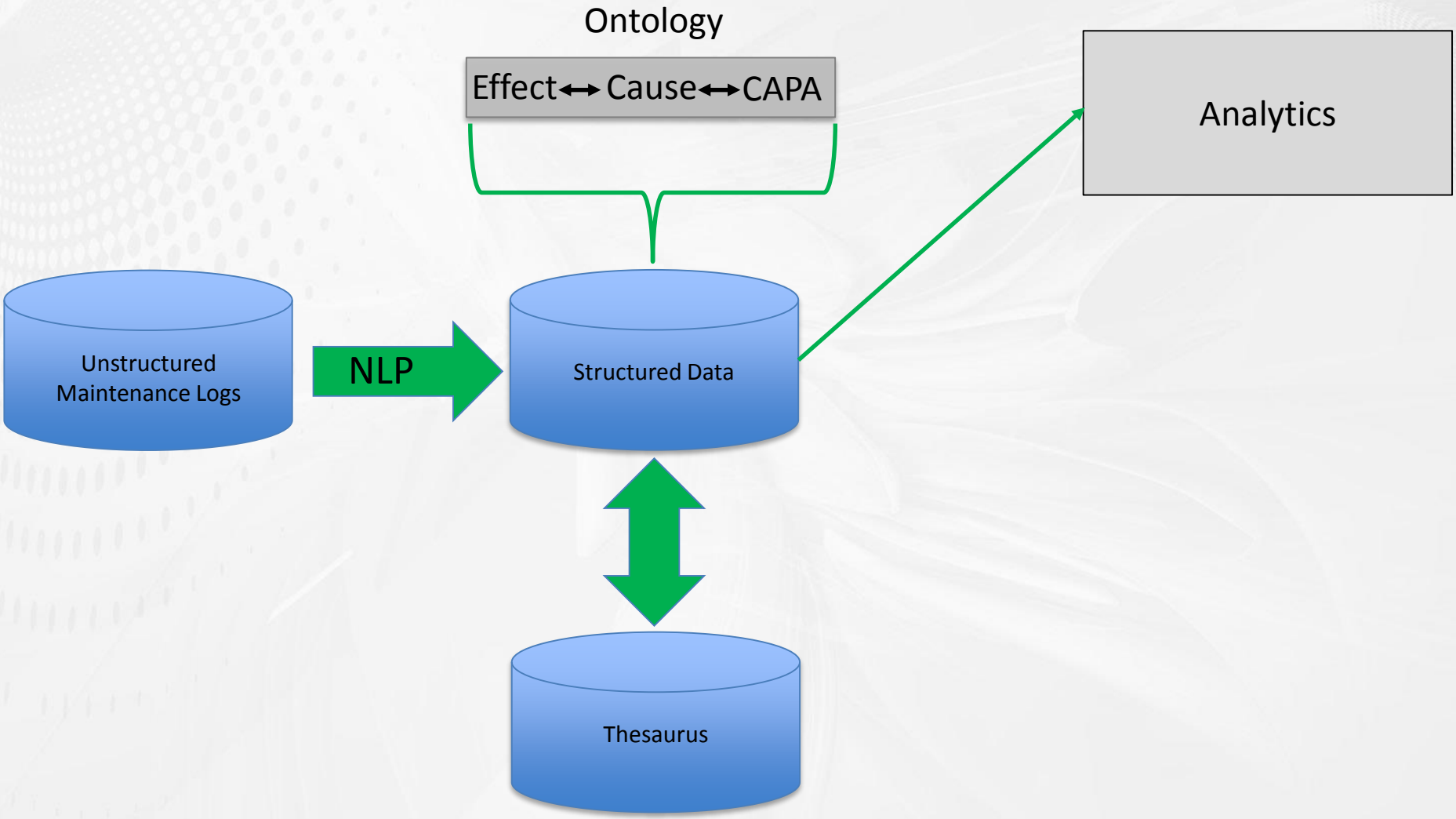


Original Data

Description	Resolution
Hydraulic Leak at cutoff unit	Missing fitting replaced

Clean Data

Hydraulic Leak	Missing Fitting	Replaced fitting	Hydraulic System	Cutoff Unit
Effect	**Cause**	**Treatment**	**System**	**Location**


Ontology
Effect↔Cause↔CAPA
Analytics
Unstructured
Maintenance Logs
NLP
Structured Data
Thesaurus

Analytics Examples: Effects

Raw Data

Effect	Average of Time to Complete (hrs)	Number of Instances	Total Time to Complete (hrs)
Accumulator check requested	1.4590	14	16.05
Vogel lube faults	1.5875	7	6.35
Base cleaning requested	13.575	4	27.15
Table index O/T faults	2.7	3	2.7
Iemca will not load in Auto	313.2	3	939.6
Chip conveyor INOP	1.075	3	2.15
Chip conveyor jammed	3.725	3	7.45
St#2 drill detector INOP	0.15	2	0.15
Table drifting at 1/2 table setting	47	2	94
Motor thermal overload fault -Hydraulic	24	2	24
Machine will not run in Auto		2	
Part not loading into collet		2	
St#8 Hyd flange not repeating	0.15	2	0.15
Power pack leak		2	
Table index O/T at 1/2 table -Turning off Hydraulics		2	

Clean Data

Effect	Average of Time to Complete (hrs)	Number of Instances	Total Time to Complete (hrs)
Hydraulic Leak	40.8775	39	817.55
Accumulator check requested	1.690	26	35.5
Coolant Leak	122.47	17	1347.2
Bearings check	16.835	16	168.35
Chip conveyor INOP	5.8	15	63.8
Broken screw	3.8722	14	34.85
Table index faults	24.08	13	120.4
Brush unit stuck forward	4.744	10	42.7
Vogel lube fault	2.27	9	11.35
Coolant Pressure Low	3.26	9	16.3
Oil leak	39.2375	8	156.95
Base cleaning requested	13.575	4	27.15
Iemca will not load in Auto	235.9	4	943.6
Bearings noise	79	4	79
Inverter failing to return	0.3	4	0.3

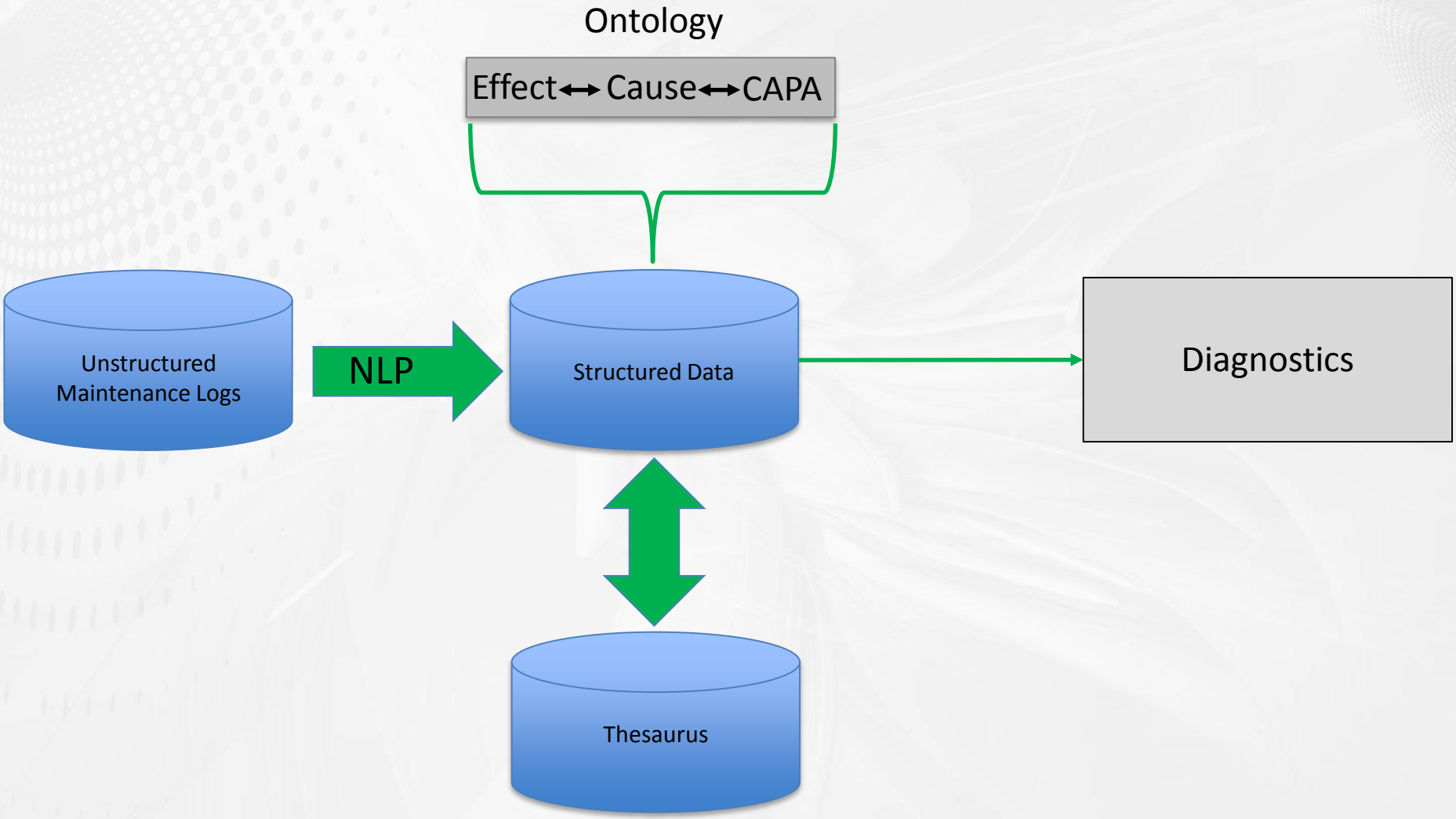
	Total Time to Complete (hrs)	
Effect	Raw	Clean
Accumulator check requested	16.05	35.5

Raw Data

Hyd leak at Bar stop pre load position
Major Hydraulic leak at Bottom XD head
Hydraulic leak at cutoff unit
Hyd leak at St#2 chip breaker valve
Hyd leak reported
Hydraulic leak at bar loader -Rubber seal on vacuum
HP Hydraulic line ruptured
Multiple leaks at Iemca -25 Gallons in 48 hours
Hydraulic return line leak
Hyd leak from behind collet #6
Hydraulic leak turret 2
Hydraulic leak actuator or horseshoe
Hydraulic leak at chip breaker valve (? Valve station)
Hydraulic leaks -from collets??
Leak at High Pressure pump
Hyd leak St#2 valve
St#6 valve leaking hydraulic
Hydraulic leak
Hyd leak at locking pin assy
Iemca hydraulic pump leaking -Full tank per day
Hydraulic leak on Side A
Hydraulic leak from power pack
St#8 valve leaking Hyd fluid
Hyd leaks -C/O unit, St#11 Valve, Collet #10 (Internal)
Hydr pump? / Power pack leak / CNCs shuddering
Hydraulic leak at inverter st#8
Hyraulic leak at St#4
Hyd leaks at valve below #7 / Lid leaks at loader
St#8 valve spraying hydraulic fluid
Hyd leak at Iemca pumps tank
Hyd leak from dressing unit
Hydraulic leak at Cutoff valve
Hydraulic leak at power pack -per PM tix
Hydraulic leak found by Doug -3.1 quill
Hydraulic Leak reported -One tank per day
Hydraulics leaking from dressing unit
Major hydraulic leak
Major Hydraulic leak at rotator -Rotator rack is broken
Hydraulic oil getting into Vogel waste oil

Clean Data

Hydraulic Leak


Ontology
Effect ↔ Cause ↔ CAPA
Unstructured Maintenance Logs
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Diagnostics
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Diagnostics Example

Observed Effect(s)

(add more effects to improve the results)

Hydraulic Leak **x** remove

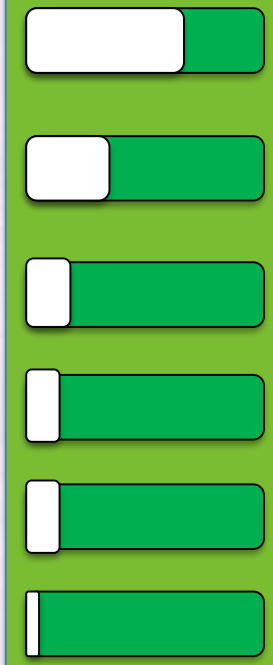
Hydraulic fluid is seen on the floor around the machine.

Related: Vogel leak? Hydraulic Parts Rack Broken? Hydraulic Alarm?

\+ Accumulator Fault | Find

Nothing else to add? Continue>

Possible Cause(s)



- Faulty valve (58%)
- Faulty hydraulic hose (20%)
- Faulty o-ring (10%)
- Missing fitting (5%)
- Loose connection (4%)
- No Problem (1%)

Diagnostics Example

Observed Effect(s)

(add more effects to improve the results)

Hydraulic Leak x remove

Accumulator Fault x remove

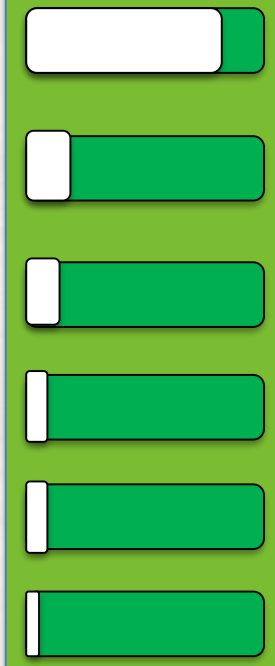
The accumulator is displaying a fault

Related: Vogel leak? Hydraulic Parts Rack Broken? Hydraulic Alarm?

\+ Enter an effect | Find

Nothing else to add? Continue>

Possible Cause(s)



Faulty o-ring (70%)

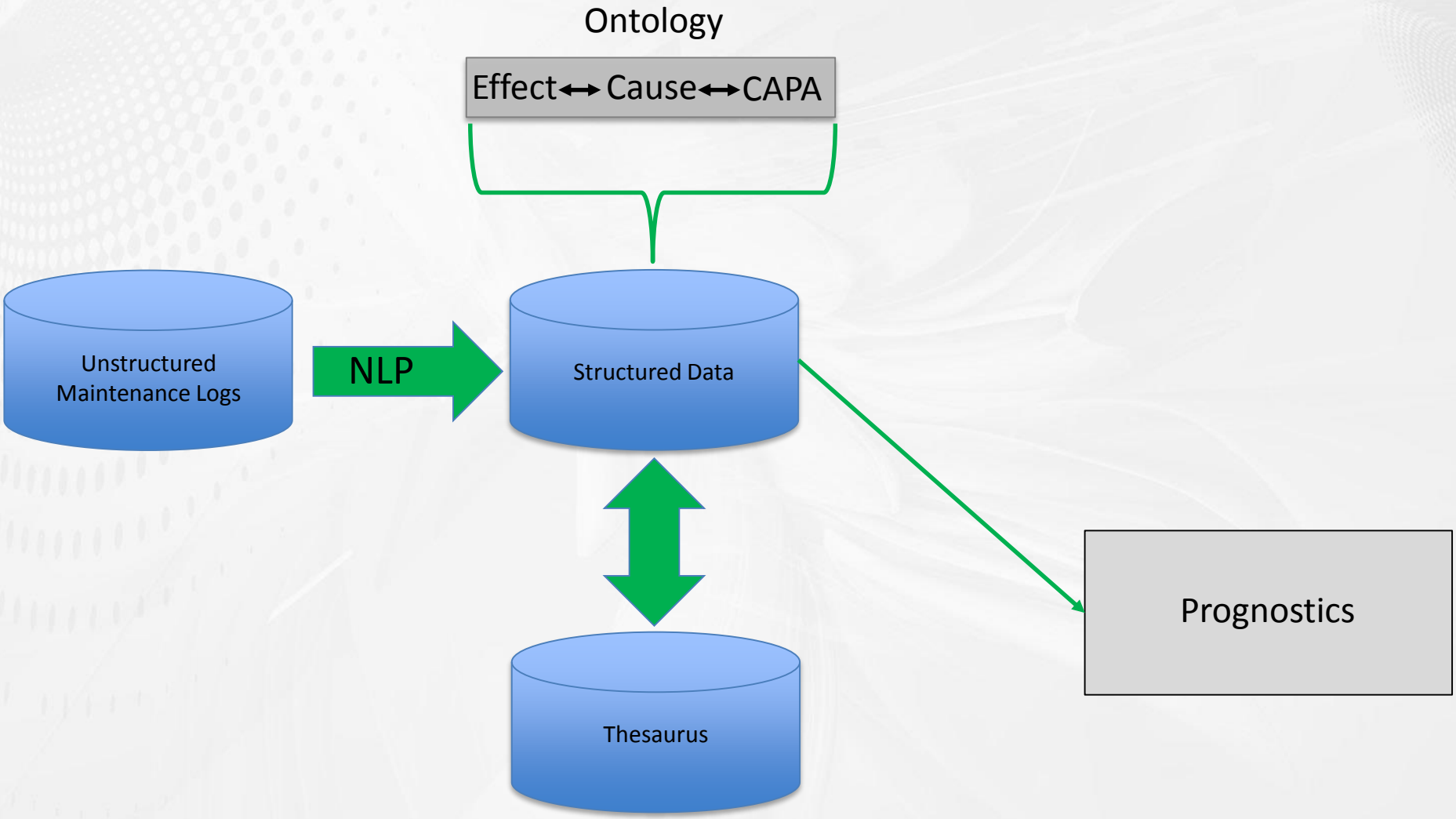
Faulty hydraulic hose (10%)

Faulty valve (9%)

Missing fitting (6%)

Loose connection (4%)

No Problem (1%)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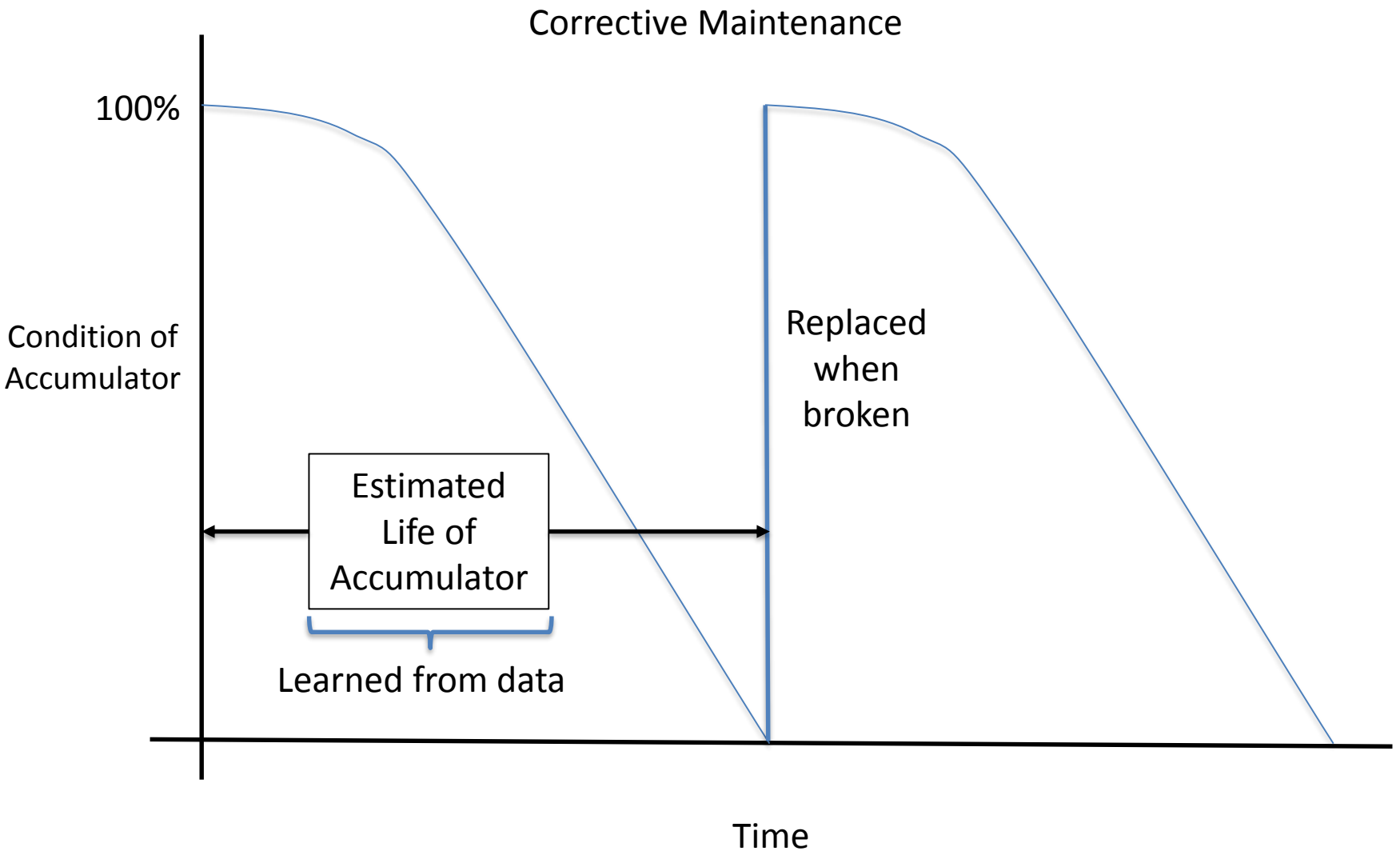
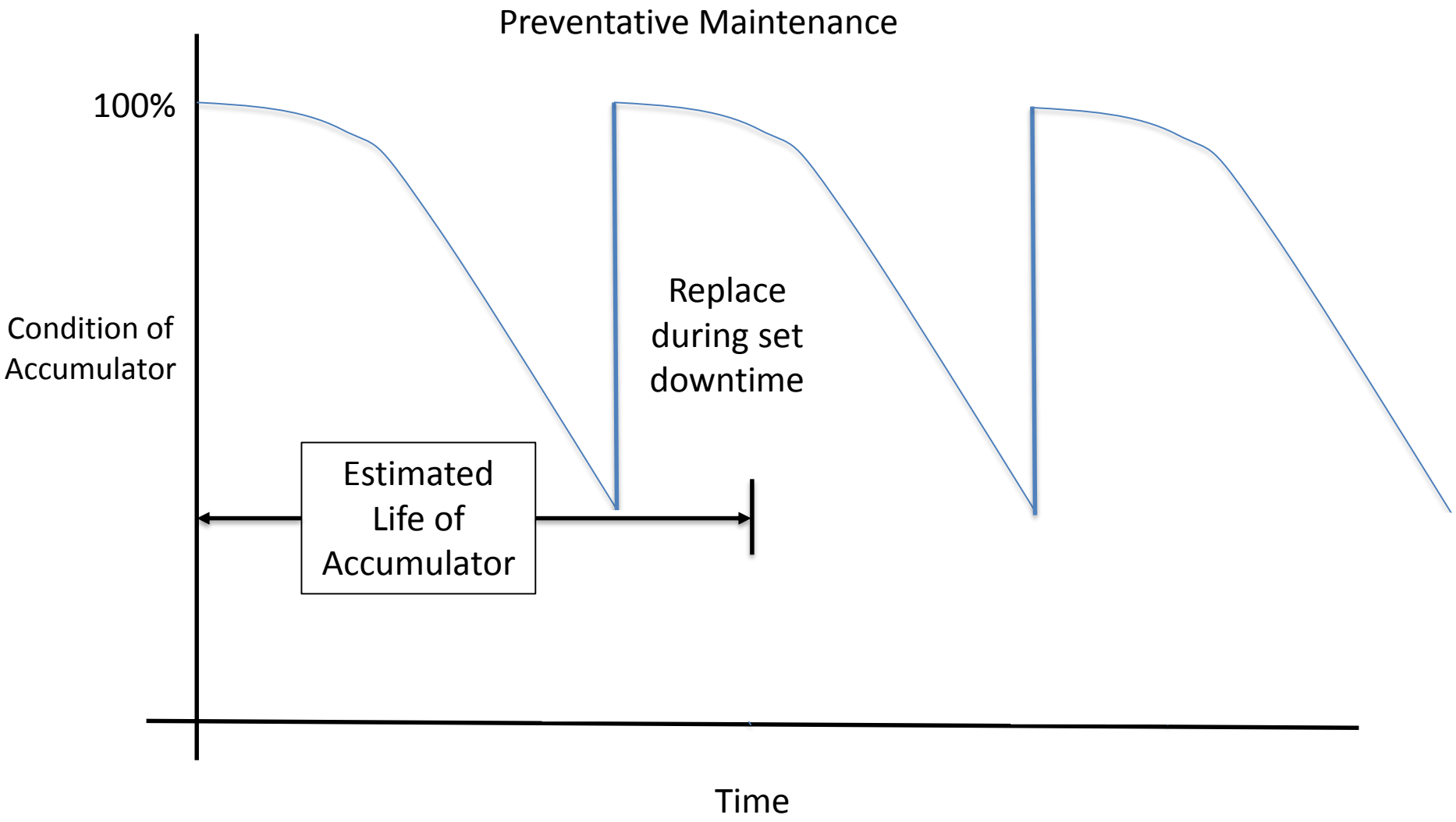
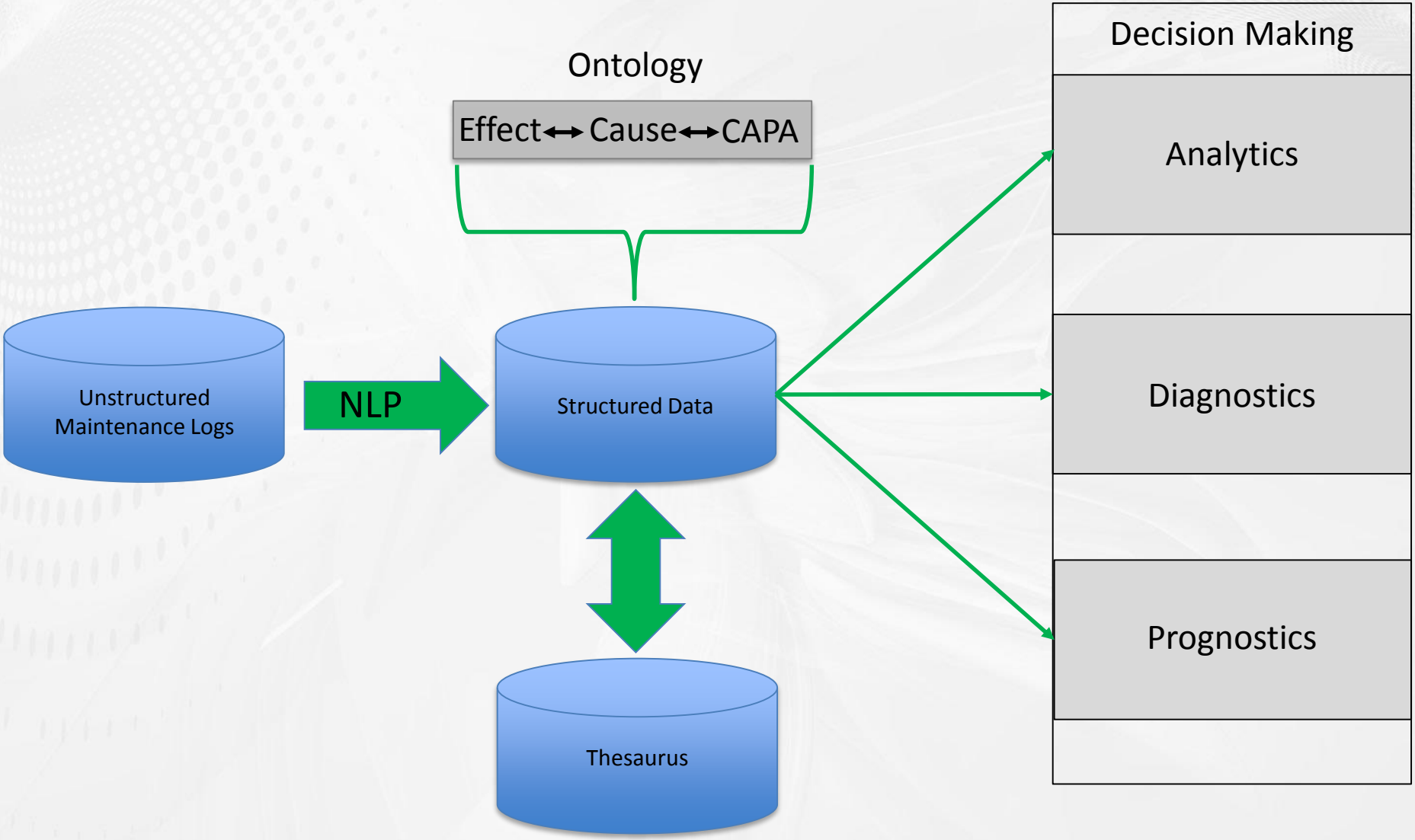
Prognostics Example: Accumulator



Prognostics Example: Accumulator

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User Input:

Hydraulic leak + Accumulator fault

Diagnostics | Analytics | Prognostics

Root Causes

Cause	% in past	Cost to Repair	Time to Repair	Estimated remaining life
Faulty Hydraulic Hose	55	$200	3 hrs	1 month
Missing Fitting	16	$100	1 hr	1 week
Faulty Seals	14	$10	0.5 hr	2 weeks
Loose Connection	7	$0	0.5 hr	3 weeks
Leaking Hose Assembly	4	$30	5 hrs	3 months
Faulty Valve	3	$500	4 hrs	6 months
Faulty O-Ring	1	$20	1 hr	2 years

Standards Strategy

- Data representation
  - Example: Control charts -> diagnostics
- How do we leverage KPIs/data to better diagnose problems
  - Enablers
    - Ontology
    - Crowdsourced knowledge
- Guide for cleaning data

Conclusions & Future Work

- More data needed to test methods
  - Maintenance Logs
  - Sensor data
  - Maintenance Manuals
- Exploring multiple NLP techniques
  - Compare with manual methods
  - Compare with crowdsourcing methods
- Validating data cleaning

Thanks for your attention…

Questions?
Objections?
Suggestions?

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