Systematic Prevention of Diesel Exposures in UG mining

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Diesel Workshop

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Introduction

Purpose of diesel exposure prevention

- Ethical considerations
- Legal requirements
- Potential benefits
  - Reduced ventilation costs
  - Comfortable work environment → increased productivity
  - Mitigation of other risks
    - Reduced risk of production shut down, fines
    - Reduced work time-lost to minor illness
    - Extended equipment life, improved reliability due to better maintenance
    - Reduced health-care expenses

Background / Motivation

True stories from the field:

- Enclosed cabs leaking, windows open, filters not installed
- Equipment operators intentionally disabling SCR sensors
- Defective DPFs remaining in-use for unknown lengths of time
- Leaks in stoppings/vent bags
- Production haulage routed through intake air
- No communication between functional departments
- New monitoring technologies being implemented non-systematically
- Decisions unsupported by data

Background / Motivation

Tough questions from the field:

- What to measure?
- How often to measure?
- Where to measure?
- How to reduce data into usable information?
- How to integrate sources of data?
- Which control option to implement (on limited $)?
- How to measure progress?

Background / Motivation

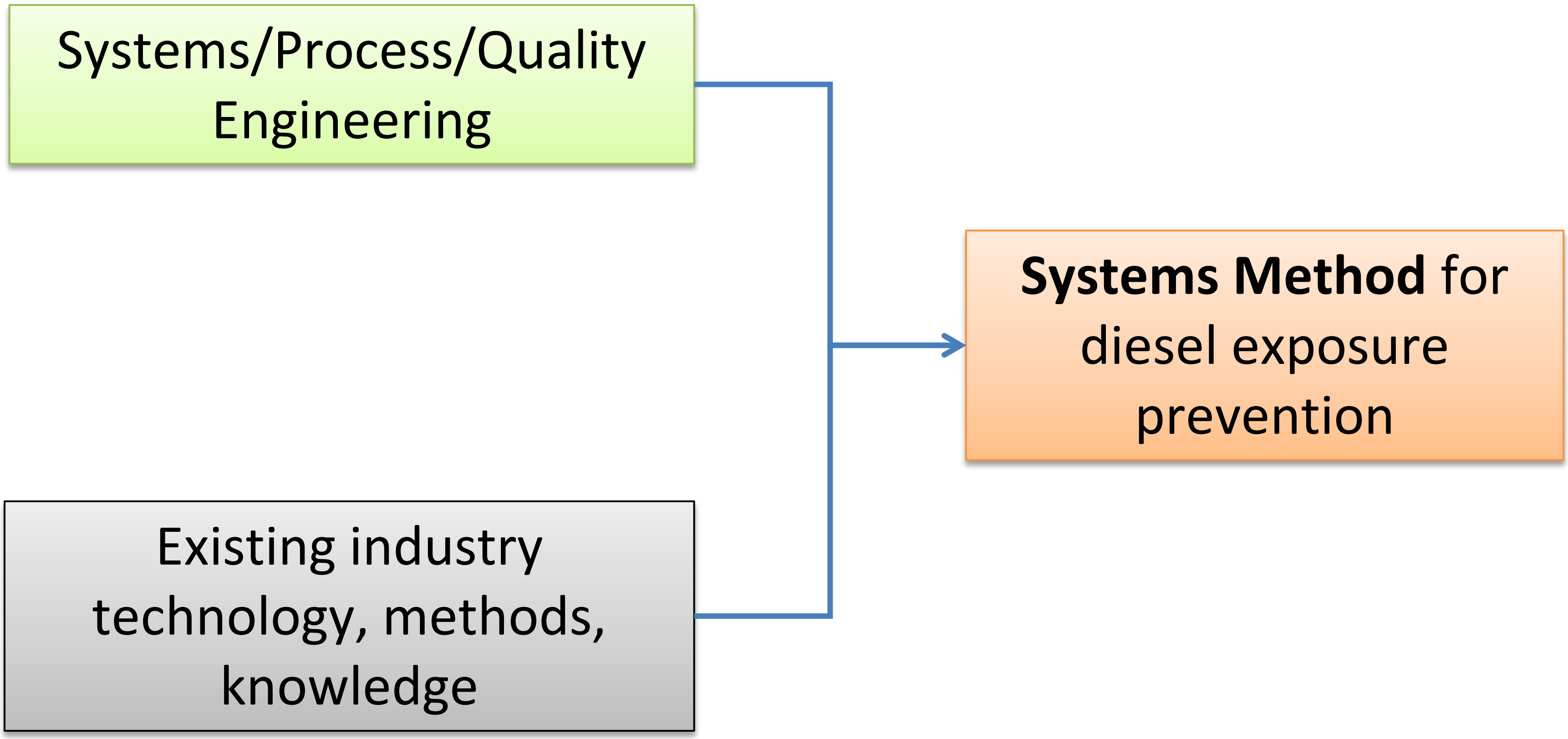
- *Systems Method* is an attempt to reduce confusion, make diesel exposure prevention easier, more effective
- Emphasis on planning and standardization of work practices
- Focus on the big picture
- Develop systems/procedures for:
  - Controlling diesel exposures
  - Acquiring measurements
  - Processing data into meaningful information
  - Linking information to control systems
  - Improving control and measurement processes
  - Documenting work activities
  - Training employees

Diesel and Processes

- Foundation is that diesel exposures are the outputs of repetitive processes (generally)
- Repetitive processes are good candidates for engineering
- Many of the issues presented are either quality control problems or measurement systems design problems
- *Systems Method* ~= Diesel Exposure Quality Control Program

Conceptual of Systems Method

Incorporate existing industry knowledge with quality/process/systems engineering concepts



Conceptualizing a Diesel Exposure Prevention Program

Conceptual overview

- Key components to any quality program
  - Measurement Systems
  - Control Systems
  - Improvement Projects
  - Training Systems
  - Documentation Systems
  - Planning and auditing

- *Systems* here is holistic. Refers to planned methods by which work is accomplished
  - <u>not</u> individual technologies and <u>not</u> random actions

- I use "systems" and "processes" interchangeably

Diesel Control Systems

Technologies, policies and routine practices that maintain exposure levels

- Administrative policies
- Standard operating procedures
- Control technologies themselves, strategies
- Maintenance of control technologies, equipment
- Plans for responding to routine monitoring data, actual responses taken
- Dashboards and monitoring tools
- and more….

Diesel Improvement Projects

Formal projects targeted at reducing exposure levels

- Selection and management of team
- Meetings, assessment of problem areas, selection of projects
- Performance of improvement projects
  - Development of solutions, selection of control technologies
  - Pilot testing solutions, optimization
  - Development of long-term control plans
- Assessment of program performance
- and more…

Diesel Measurement Systems

All relevant data that is collected and the associated processes, technologies and analyses used

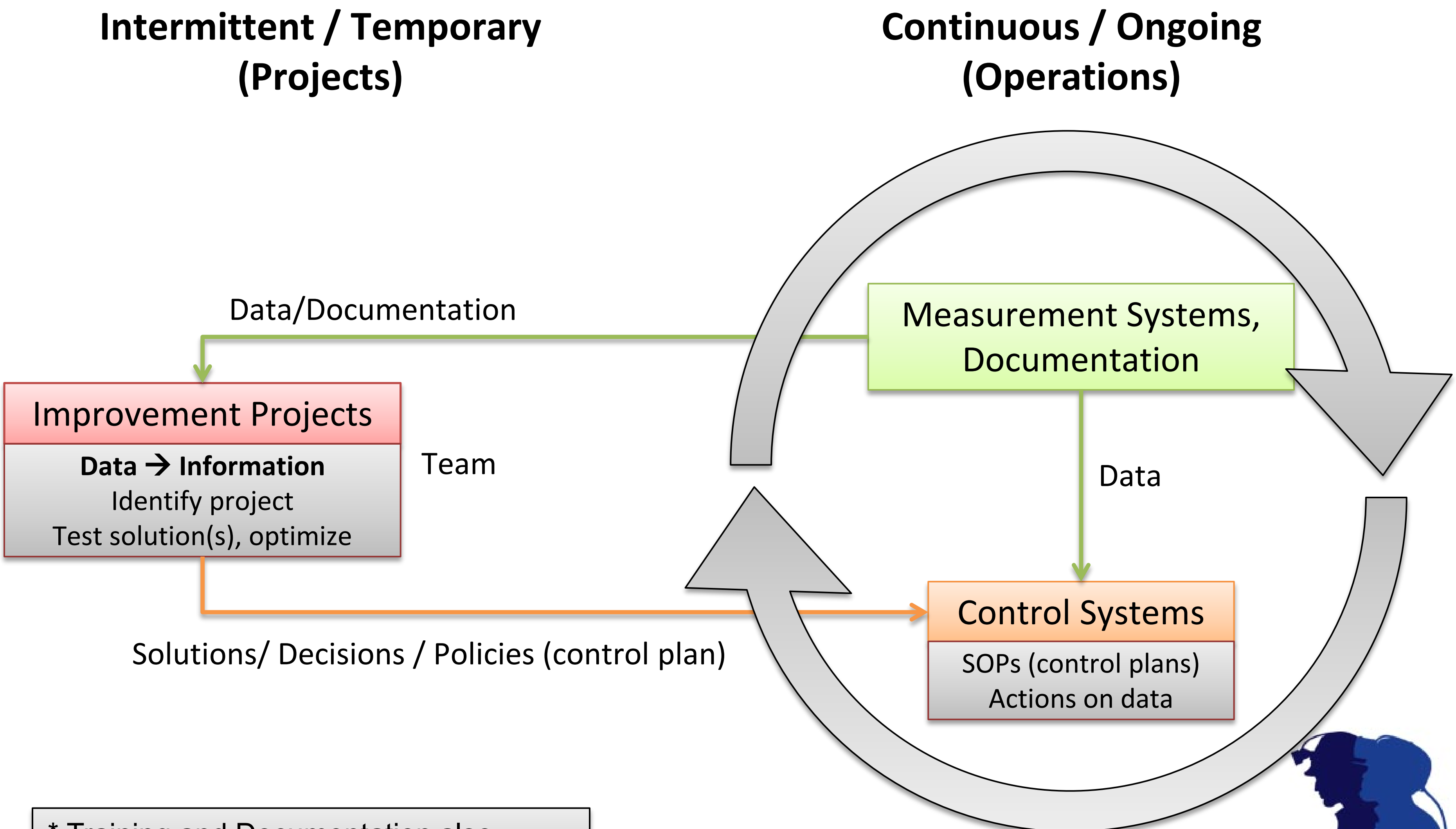
- Data for control systems and projects
- Data collection and analysis procedures
- Handling of data (transfer of data and information, storage, backup)
- Sensors/Instruments themselves
- Instrument calibration procedures, maintenance of instruments
- and more….

Training Systems

Anything that is planned and attempts to improve a workers' competence in an aspect of diesel exposure prevention

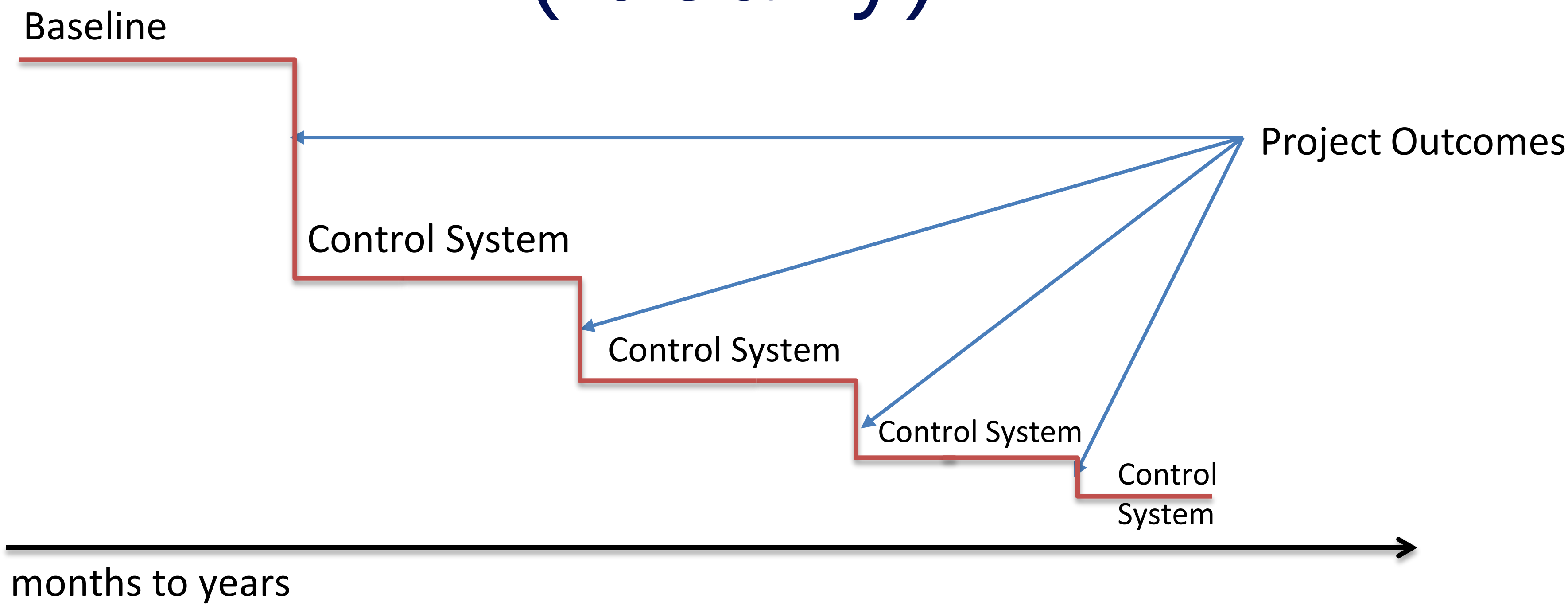
- Formal training courses/lessons
- Informal, continuous (on job) training / mentoring
  - A form of planned training
- Leadership development methods
- Visual information tools, signs
- Safety culture initiatives

A Quality Program ConOps



* Training and Documentation also ongoing, Auditing intermittent

Continuous improvement (ideally)



- **Improvement Projects** provide gains (informed decisions and strategies)
  - Improvement team develops control plans
- **Control system** maintains those gains, prevents relapses
- **Measurement system** provides data for both
- **Training system** provides capable workers / culture for both
- **Documentation** keeps everyone abreast of changes, reduces confusion
- **Auditing** identifies deficiencies in program, keeps on track

Operationalizing a DPM Quality Control Program

"A problem well stated is a problem half solved." – Charles Kettering

QC/QI Cheat Sheet

1) Define and understand processes
    1) Personally observe and record them
    2) Map them
    3) Determine what aspects should be measured & controlled, how
    4) Audit your ability to acquire sound measurements (gage R&R study, calibration)
    5) Implement the measurements
2) Establish process requirements/specification limits
3) Monitor and control the process (ongoing)
    1) Record data, transform into info
    2) Review/monitor the info
        1) Ensure that the process is operating within limits
        2) Take actions to bring the process back to spec when necessary
        3) Document actions taken
4) Improve the process incrementally (ongoing)
    1) Review data, identify potential improvement options
    2) Test and optimize solutions
    3) Pilot the solution
    4) Develop a control plan and implement the solution
    5) Update process maps, document changes
5) Measure and assess long term progress (ongoing)

Observe the process

Importance of in-person observation:

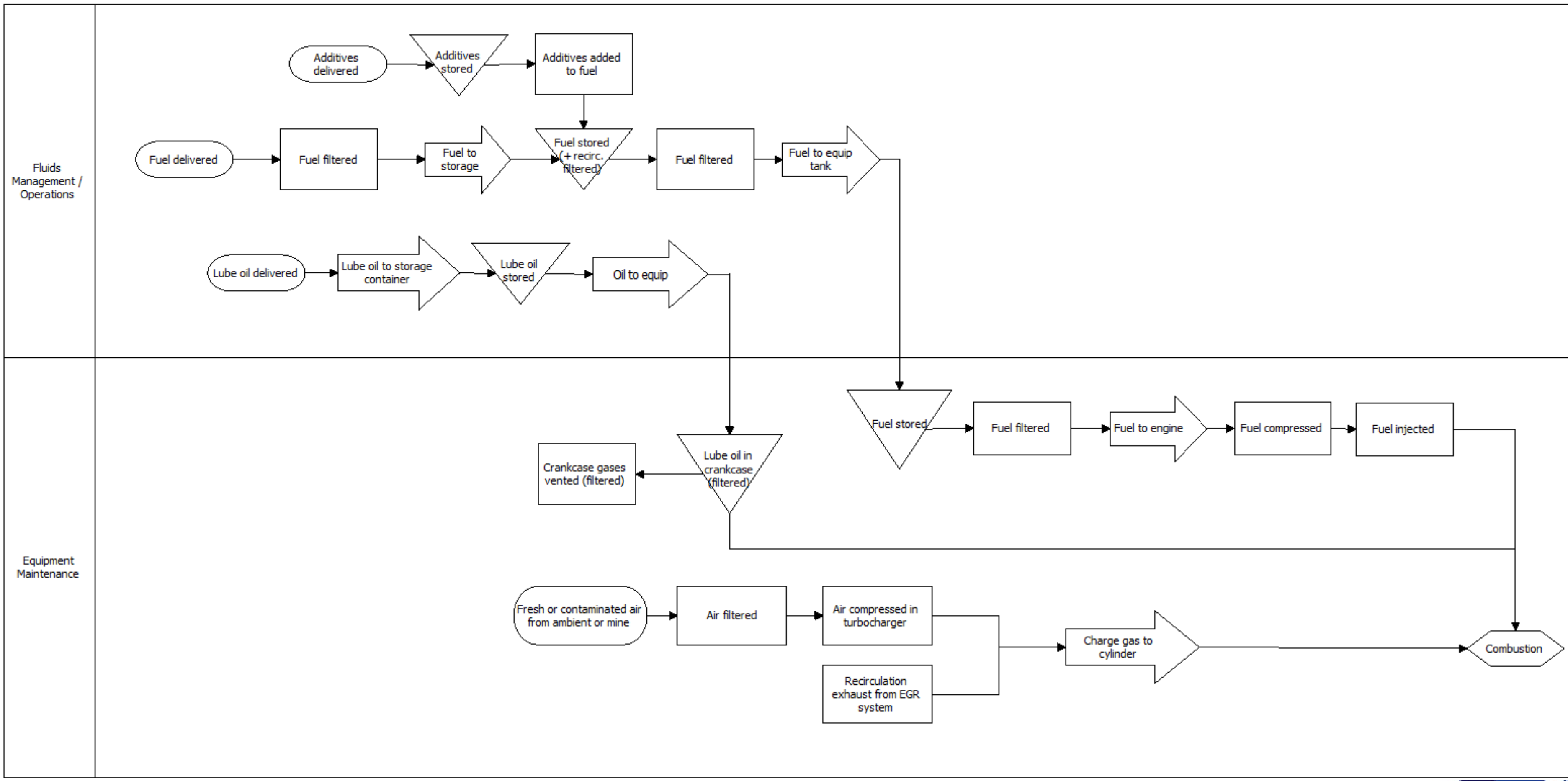
- Goal is to document the “as-is” state of things, as opposed to the “should-be” state of things
- Asking others how a process works or relying on company documentation often gives you the “should-be” version
- Where in-person observation is not practical, monitoring data/measurements are the next best substitute
- Lesson: <u>Always stay skeptical</u> (even when you are certain)

Map the Processes

- Each functional unit at a mine should define and understand how their processes work
- Members on improvement team should understand the entire system
- Goal is to produce a map that will help with process control & improvement and to wrap your head around the process
  - Trying to define too much where uncertainty exists is waste
  - Conceptual liberties may need to be taken to simplify maps
  - The act of developing the map is an excellent form of training
- Maps are also good starting points for control dashboards

Map Processes

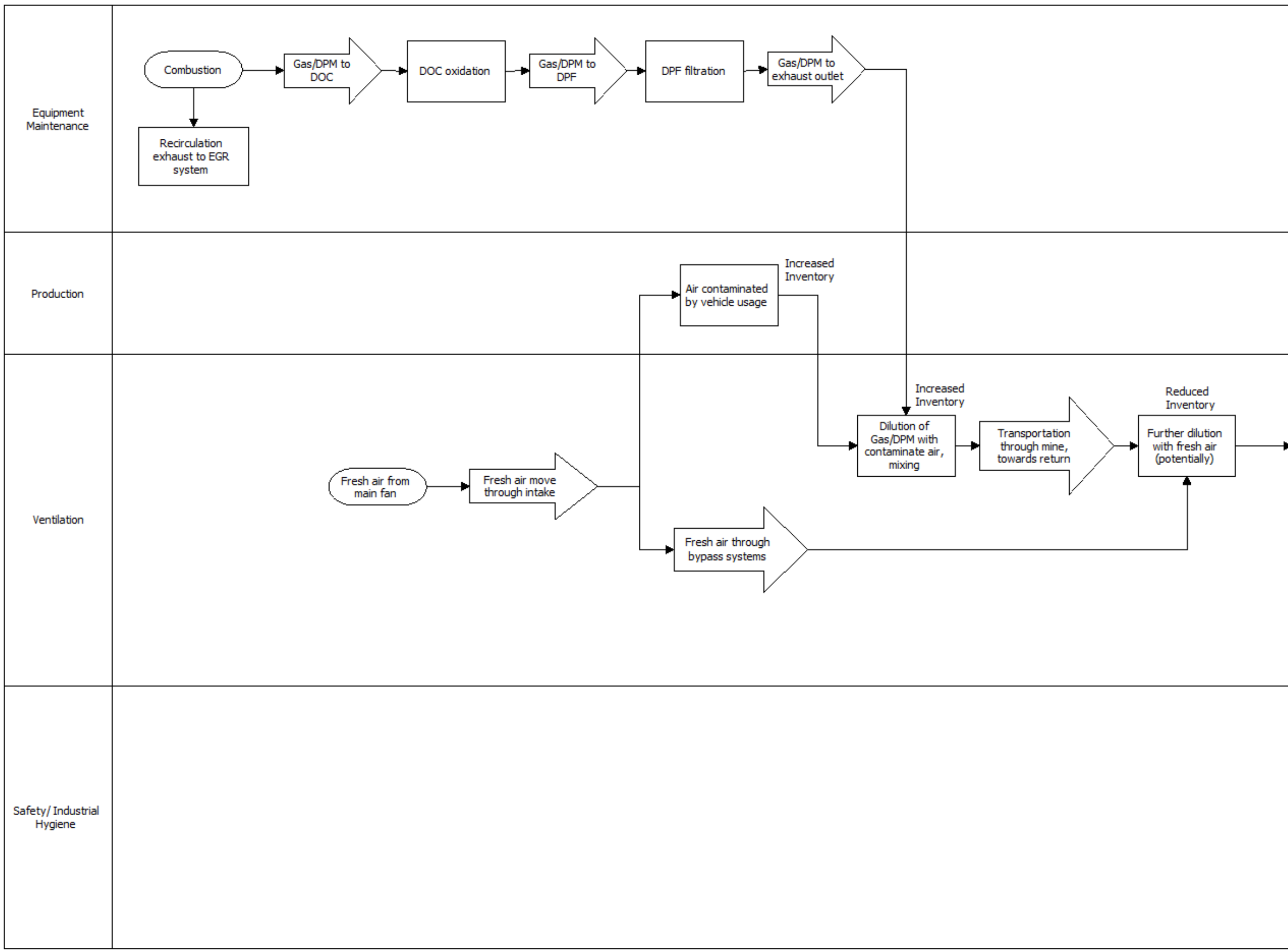
- Example high-level lifecycle process map of diesel exposures at an UG mine operation (pre-combustion portion)



Map Processes

- High-level post-combustion processes (part I)

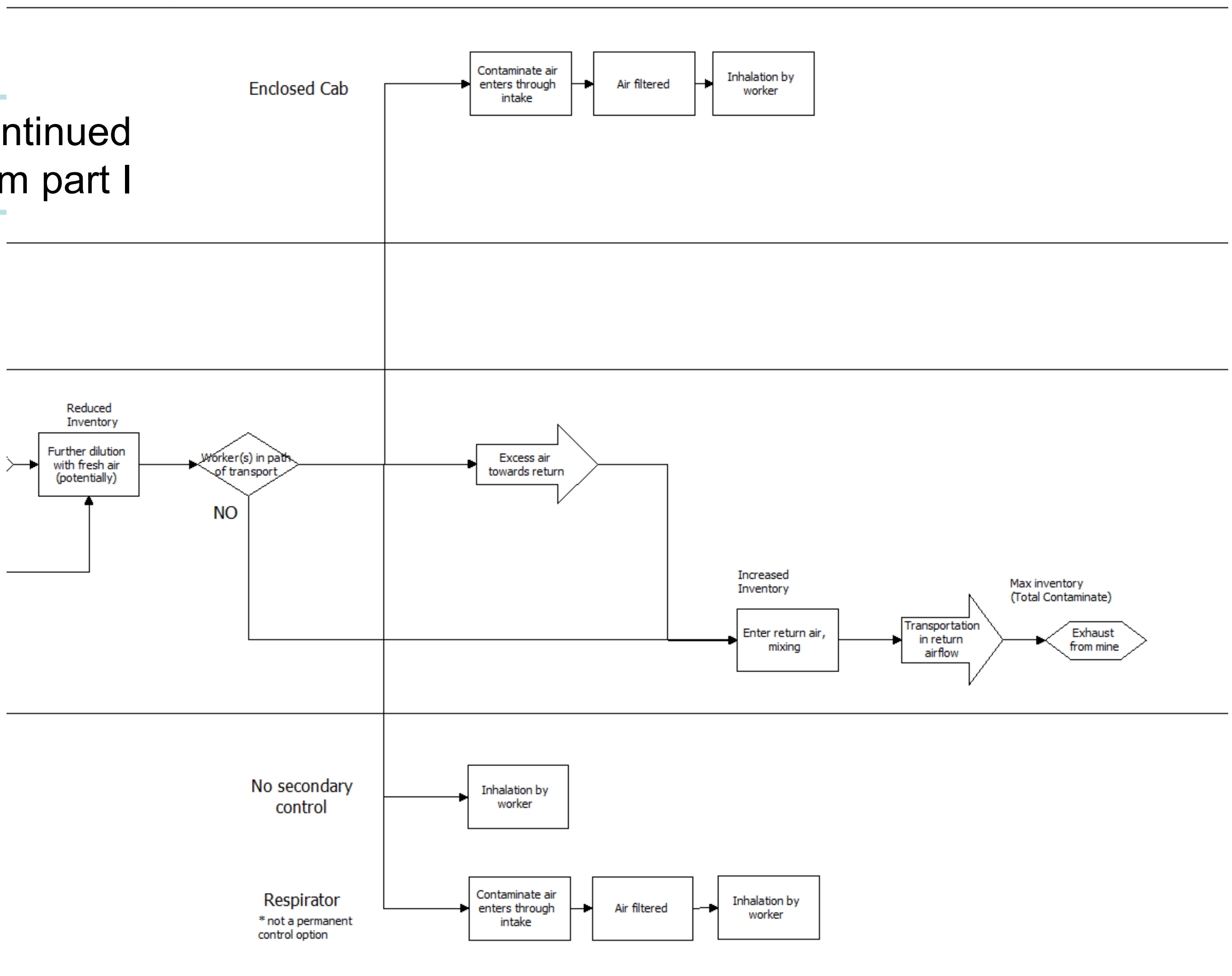
Continued from pre-combustion map



Map Processes

- high-level post-combustion processes (part II)

Continued from part I



Decide what to measure & control

- Use the information in the map to develop a measurement and control system
- Risk analysis is commonly used to determine what should be measured (or directly controlled) in the process
- Process Failure Modes and Effects Analysis (FMEA) is a popular approach
  - Note: there are variants of this depending on if you are designing a new measurement/control system or auditing an existing one. In this example assume the purpose is to redesign existing measurement and control systems

Process FMEA

- For each step in process map ask, "How can this step go wrong?" (in terms of controlling worker exposure to diesel)
  - This results in a list of potential **failure modes**
- For each failure mode ask, "What is the impact on worker exposures/safety?"
  - This is the SEVERITY rating (1-10, 10 = most severe)
- For each failure mode identify potential causes of the failure
  - Consider using the following categories:
    - » Man, Machine, Methods, Measurements, Materials, Environment

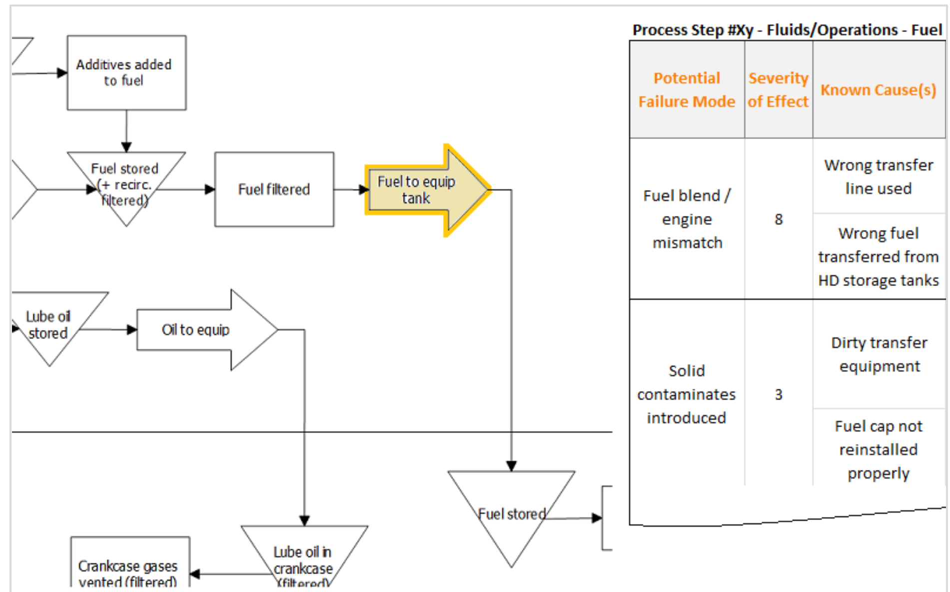
Process FMEA

Example process step:
Transferring fuel from bulk storage container to tank on equipment

Potential Failure Modes (example only):

1. Wrong fluid used (Severity = 8)
- Potential causes
    - Wrong transfer line used by operator
    - Wrong fluid in bulk storage container to begin with
    - Etc…

2. Solid contaminates introduced (Severity = 3)
- Potential causes
    - Dirty transfer equipment used
    - Fuel cap not properly reinstalled
    - Etc..



This results in a list of **potential causes**

Process FMEA

- For each potential cause, ask "What is the likelihood of occurrence?"
  – This is the OCCURRENCE rating (1-10, 10 = most likely)

- For each potential cause, ask "What is the likelihood of detection?" (in our current system)
  - This is the DETECTIBILITY rating (1-10, 10 = least likely)
  - **Note:** This rating is an inverse

- Calculate the risk priority number (RPN) for each cause
  - RPN = SEVERITY x OCCURANCE X DETECTIBILITY

Decide what to measure & control

- Focus on causes with SEVERITY=10's and highest RPN scores first
- List monitoring and control options for every major cause
  - Brainstorm for preventative controls (error-proofing/error-avoidance) and other control options
    - Ex. Trigger equipment shutdown or light if fuel cap not properly reinstalled
    - Ex. Color code fuel transfer equipment and transfer points
    - Ex. Install different mating for different fluids
- Decide on best controls/measures
- Develop an implementation plan and assign responsibility
- Implement and document the actions taken
- Re-compute RPN scores

Example FMEA

Process or Product Name:

Responsible:

Prepared by Page ___ of: ___

FMEA Date (Orig) ______________ (Rev)

Process/Product FMEA Form

Process Step / Input	Potential Failure Mode	Potential Failure Effects	SEVERITY	Potential Causes	OCCURRENCE	Current Controls	DETECTION	RPN	Actions Recommended	Resp.	Actions Taken	SEVERITY	OCCURRENCE	DETECTION	RPN
What is the process step and Input under investigation?	In what ways does the Key Input go wrong?	What is the impact on the Key Output Variables (Customer Requirements)		What causes the Key Input to go wrong?		What are the existing controls & procedures (inspection and test) that prevent either the cause of the Failure Mode?			What are the actions for reducing the occurrence of the cause, or improving detection?		What are the completed actions taken with the recalculated RPN?				
Fill carafe with water	Wrong amount of water	Coffee too strong or too weak	8	Faded level marks on carafe	4	Visual inspection	4	128	Replace Carafe	Mel	Carafe replaced	8	1	3	24
			8	Water spilled from carafe	5	None	9	360	Train employees	Flo	Employees trained	8	2	7	112
	Water too warm	Coffee too strong	8	Faucet not allowed to run and cool	8	Finger	4	256	Train employees	Flo	Employees trained	8	2	6	96
			8	Employee not aware of new need for cool water	7	None	10	560	Train employees	Flo	Employees trained	8	1	8	64
	Carafe not clean	Foreign objects in coffee	10	Carafe not washed	4	Visual inspection	4	160	Appoint inspector before storage	Alice	Vera is the new inspector	10	1	4	40
		Bad taste	10	Carafe stored improperly	7	training	5	350	Create storage bin & train employees	Alice	New storage bin & employees trained	10	2	3	60

FMEA scale criteria

Potential scales and ratings criteria, derived from auto industry

SEVERITY (criteria removed intentionally)

Effect	Ranking	Sample criteria
Hazardous without warning	10	Immediate safety threat
Hazardous with warning	9	Immediate safety threat (with warning)
Very High	8	Failure leads to over-exposures in 100% of workers
High	7	
Moderate	6	
Low	5	
Very Low	4	
Minor	3	
Very Minor	2	
None	1	No effect

OCCURENCE

Probability of Failure	Ranking	Sample criteria: Failure rate
Very high: Failure is almost inevitable	10	> 1 in 2
	9	1 in 3
High	8	1 in 8
	7	1 in 20
Moderate	6	1 in 80
	5	1 in 400
	4	1 in 2000
Low	3	1 in 15,000
Very Low	2	1 in 150,000
Remote	1	< 1 in 1,500,000

DETECTIBILITY

Detection	Ranking	Sample Criteria: Likelihood of Detection by Process Control
Almost impossible	10	No known control available to detect failure mode.
Very Remote	9	Very remote likelihood control/measure will detect failure mode.
Remote	8	Remote likelihood control/measure will detect failure mode.
Very Low	7	Very Low likelihood control/measure will detect failure mode.
Low	6	Low likelihood control/measure will detect failure mode.
Moderate	5	Moderate likelihood control/measure will detect failure mode.
Moderately High	4	Moderately high likelihood control/measure will detect failure mode.
High	3	High likelihood control/measure will detect failure mode.
Very High	2	Very high likelihood control/measure will detect failure mode.
Almost Certain	1	Current controls almost certain to detect the failure mode. Reliable detection controls are known with similar processes.

Scales based on *FMEA Manual (Chrysler, Ford, General Motors Suppler Quality Requirements Task Force)*

Notes on FMEA and measurements

- Specific criteria should be developed for each ranking
  - Reduces biases
  - A 1 to 5 ranking scale may be easier to reach a group consensus

Notes on FMEA and measurements

- **Procedure outlined here focuses on designing measures of <u>the process</u>**
  - Primary purpose is to monitor operations and deploy corrective actions when failures in the processes occur

- **A complete measurement system would also include <u>surveillance data</u> to estimate worker exposures (e.g. area and personal exposure measurements)**
  - These are measures of the *outputs of the process*
  - Useful in identifying improvement initiatives and assessing quality program progress
  - Surveillance data can be less useful for taking immediate corrective actions
    - Long control loops (historically)
    - Confounding information

Notes on measurements

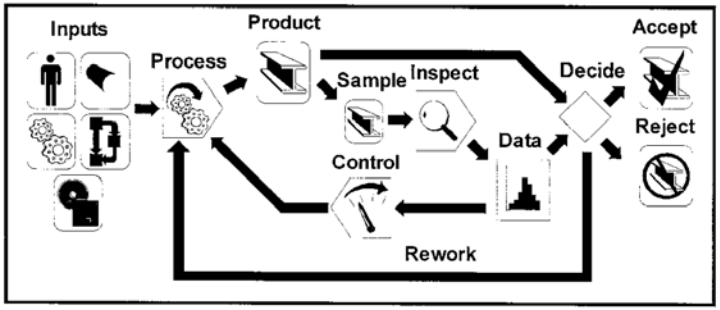


Fig. 2. SQC inspections begin with a sample drawn from products downstream of a process.

Data from the inspected sample is collected and described statistically. Data are used to provide feedback control for the process and to decide whether the product or lot is accepted, rejected, or submitted for rework.

(Hinckley, 1997 - Defining the best quality-control systems by design and inspection)

Downstream

Measure the <u>outputs</u> of a process

Measuring worker DPM exposure
Measuring DPM concentration in an area

Good for assessment purposes, but…..

1. Control loop is long! (*unless electronic/computerized)
2. Difficult to know what's causing the problem
3. If data is limited, no good for monitoring processes that vary significantly over time

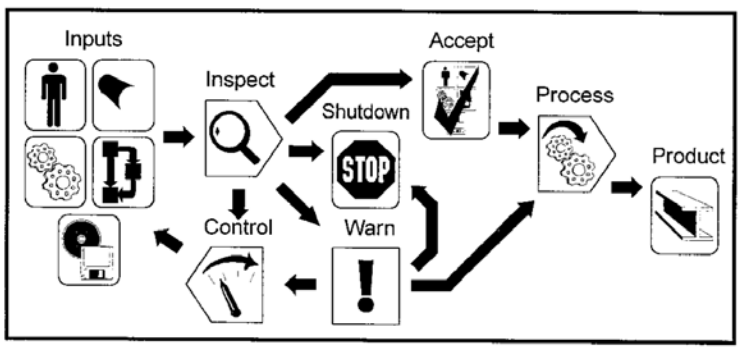


Fig. 3. Source inspections verify that all of the inputs to a process are acceptable before the process is executed.

If any of the inputs are not correct or if any mistakes have been made in the setup, action to stop, warn, or control the inputs is taken before the process is executed. When the inputs are accepted, the process is executed without the need for downstream inspection.

Upstream

Measure the <u>inputs</u> of a process

Monitoring enclosed cab pressure
Monitoring engine backpressure (DPF integrity)

Good for control purposes

1. Control loop is short!
2. <u>Directly measure the source(s) of problem</u>
3. Can save time and energy

However….
Can be difficult to implement
Can be difficult to reduce data for assessment purposes

Notes on measurements

- Unfortunately, not many recommendations for designing exposure surveillance measurement systems at the moment
  - Part of ongoing work at NIOSH
  - Most industry information focuses on how to use equipment, not sampling plan strategy
  - Can look to sampling plan theory, ASQ, MSHA, OSHA and IH references for help
  - Difficulty stems from overhead of collecting data, limited # of data
  - New tools can help in this area
  - Willingness to accept estimations can also help

Developing metrics

- All measures must be operationalized
- Dimension → Measure → Metric
    - DPF reliability → Frequency of failure → Mean time between failures
    - Individual DPF integrity → Current engine backpressure → psi
    - Vent bypass maintenance → How responsive are repairs → Mean time between leaks identified and leaks repaired
    - Diesel QC program impact → Reduction in worker exposures → % of non-compliant personal samples per quarter

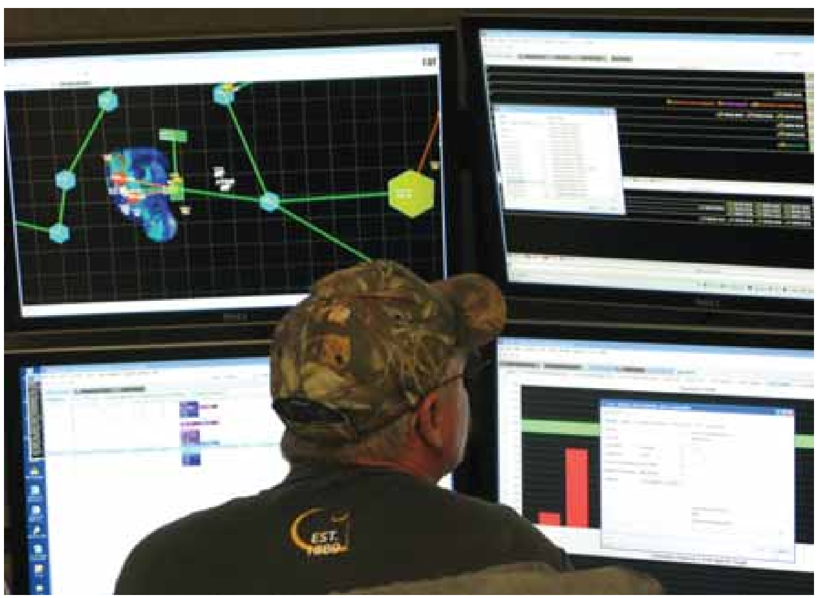
- A living database of metrics used in the industry would be a good idea

Establishing operating limits

- Determine metrics and begin collecting data as part of normal operations
- Once enough data is acquired, chart this data (if possible)
  - Process data provides best info when charted over time
- From there, you can gauge and establish realistic requirements/specification limits
  - Other factors to consider
    - maintenance requirements of equipment involved (manufacturer established)
    - regulatory requirements

Monitor and control the process

- Execute standard operating procedures
- Perform routine data collection and analysis
- Make use of Error-Proofing, Dashboards and Control Charts whenever possible
  - **Control charts** ensure that you don't act on random variation (noise)



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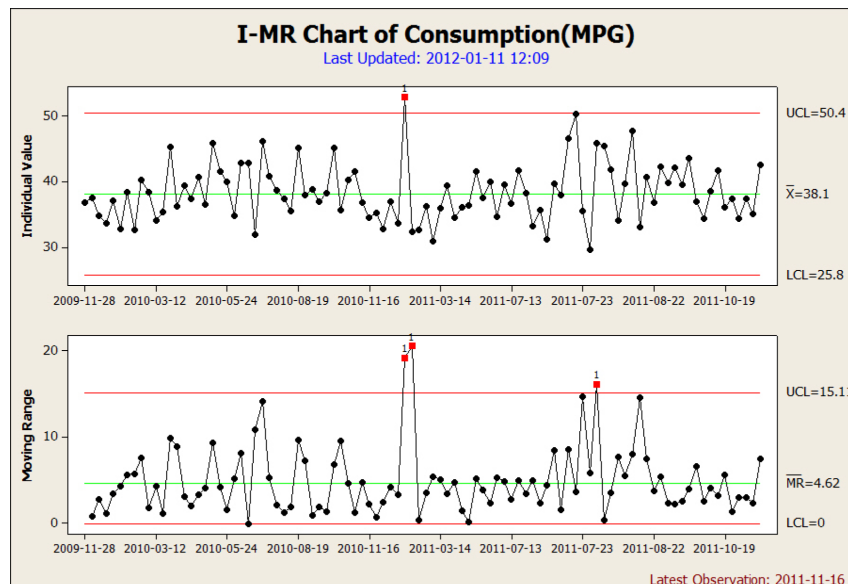

Image Source Credit: http://minitabmaestro.com/

Monitor and control the process

- **Don't let quality problems persist**
  - reduced DPM inventory → reduced DPM exposures
  - Have mechanisms in place to process failures as fast as possible!
  - Conceptually, rate of DPM reduced by corrections must be greater than the rate of DPM generated by problems (Otherwise inventory builds, exposures increase)

Monitor and control the process

- **Prevent error/variation**
  - It is far better to design quality into processes than to try and find problems through inspection
  - Standardization of work practices reduces error, reduces variation and increases efficiency
    - Develop SOPs/policies, train workers, ensure practices are followed
  - Make use of error-avoidance and error-proofing when possible
    - Ex. Vehicle can’t be operated with windows, doors open
    - Ex. Instructions/indicators located directly on equipment
    - Ex. Hygienist wraps personal sampling line so that it can’t kink
    - Ex. Electronic tag board, doors, limits X# of vehicles in an area at a time

    **** Careful not to create another problem or dangerous scenario!**
  - Organize work areas (5S method, this also improves efficiency)
  - Consider designing redundancy into key/unreliable components

Monitor and control the process

- **Other advice**
  - Upstream measurements when possible/sensible
  - Limit # of measurements to what is necessary and manageable (excess measurements are typically considered waste)
  - Use dashboards, visual management when possible
  - Be open to new technology, but cautious
    - Adopt only when simpler/more effective than “stone age” methods

Monitor and control the process

- **Other advice**
  - Randomize routine measurement schedules when possible
    - This reduces chance of artifacts in data
    - Make use of random number tables
  - Implement documentation systems
    - Changes that affect diesel prevention processes <u>must</u> be recorded
    - Don't over-document (waste)
    - Use your documentation!
      - Documentation is supposed to be a tool, not a waste of time
      - Improvement team needs to know what changes were made to the system. Likewise for HSMS audits.

Improve the process incrementally

- **Team approach** is most commonly used in quality improvement
  - Some mines already have these for improving operational efficiencies
  - There may also be a good business case for diesel exposure prevention

- Team should be composed of cross-functional members
  - Representatives from Management, Safety/IH, Ventilation, Maintenance, Production.

Improve the process incrementally

- Good traits for team members to have:
  - Buy-in, belief in the program & concepts
  - Can-do attitude
  - Basic data processing and/or analysis abilities
  - Actual authority to implement change in his/her department
  - Ideally, team members should have some training in quality engineering, lean and six sigma
    - At least one person must have expertise in these (lead role)
- Team must have real authority
  - Roadblocks must be removed
  - Must be allowed to test and implement changes
  - Oversight is good, best to involve leadership in the process

Improve the process incrementally

- Team meets and reviews current performance information
  - Potentially….
    - DPM surveillance by work function from IH
    - Environmental measurements collected from Ventilation
    - Maintenance performance and emissions measurements from Maintenance
    - Long-term program performance

- Team reviews documentation from each department
  - Keep informed of changes in processes, equipment, etc.

- Team reviews progress of current improvement projects

Improve the process incrementally

- Team identifies potential improvement initiatives (projects)
  - For high-cost/complex projects
    - Testing and piloting plans would be made, ownership assigned
    - Use DMAIC (six sigma) approach as a guide
  - For low-cost/simple control solutions
    - Policies, control plans implemented immediately, ownership assigned
    - Use PDCA approach as a guide

Improve the process incrementally

- Members prepare info before meeting, come with ideas (hopefully)
  - Reduce data to information (charts, diagrams) as part of routine work
  - Consider correlation with measurements from other departments
  - Should have read-only access to raw data and documentation from other departments

- This should not require the use of "space age" statistical tools
- The improvement "way of thinking" is considered much more important
  - "Space age" statistical tools rarely used in practice
  - Likewise, training should not focus primarily on statistical tools
  - 8 most used quality tools are:
    - Flowchart (map), fishbone diagram, check list, control chart, histogram, Pareto chart, scatter diagram, stratification

- Design of Experiments is also something to consider when planning new projects

Improve the process incrementally

- After a project is performed and piloted, and results are verified, it is ready to be scaled up

- A formal/written control plan must be developed
  - This is composed of operating procedures, maintenance requirements, control measurements
  - A long-term process owner is identified

- Control is then handed over to process operators and owner
- Process operators follow the control plan as part of routine operations
- Process owner monitors the control via performance data, reports to team

Assess long-term performance

- Leadership and Team should track the progress of the Diesel Exposure Prevention Program over time

- Determining what metric to use is the most important/difficult aspect
  - Decide on this during program planning so that necessary measurement systems can be established
  - Need a satellite level measure, should properly express the "big picture"
  - Difficult to say what is best, needs researched further
  - May need multiple measures/metrics
  - **Don't** just take the average concentration of personal exposure measurements!

Assess long-term performance

- Use control chart(s) to track progress and assess over longer time intervals
- Give the program and team time. It may take several months just to get a baseline satellite-level measurement

Assess long term performance

- Other tools, things to consider
- Process Capability Maturity Rating

Level 1 - Initial (Chaotic)

Processes are undocumented, in a state of dynamic change, tending to be driven in an ad hoc, uncontrolled and reactive manner by users or events. **Individual heroics** might be keeping the processes functioning.

Level 2 - Repeatable

Some processes are repeatable, possibly with consistent results. Process discipline unlikely to be rigorous, but may exist in some aspects

Level 3 - Defined

Sets of defined and documented standard processes are established and subject to some degree of improvement over time. These standard processes are in place.

Level 4 - Managed

Using process metrics, management can effectively control the AS-IS process. Specification are in places and process are controlled and operated within specifications. Process Capability is established from this level.

Level 5 - Optimizing

Processes are managed and are also continually improved through both incremental and innovative technological changes/improvements.

Assess long term performance

- Other tools, things to consider

- Audits / Standards / Training
  - Health and Safety Management Systems (HSMS)
    - Usually variants of ANSI Z-10 or OHSAS 18001, ISO-9001
    - CORESafety.org looks promising
      - Training, expectations of systems, metrics
    - If HSMS are not descriptive enough, ISO-9001 is also a good set of standards to try to meet (rigorous though)

Selected reading

- ASQ.org (American Society for Quality)
- Besterfield et al. Total quality management. Upper Saddle River, N.J: Prentice Hall, 1999.
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- Arthur. Lean six sigma for hospitals. New York: McGraw-Hill, 2011.

More NIOSH diesel research

Go to Diesel Team Home Page Directly:
http://www.cdc.gov/niosh/mining/topics/topicpage2.htm

-Or-

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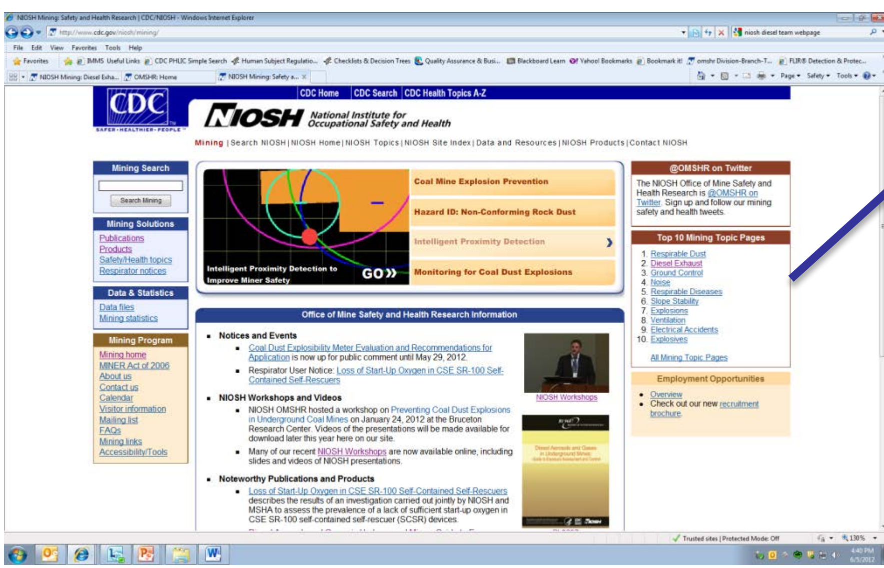

Top 10 Mining Topic Pages

1. Respirable Dust
2. Diesel Exhaust
3. Ground Control
4. Noise
5. Respirable Diseases
6. Slope Stability
7. Explosions
8. Ventilation
9. Electrical Accidents
10. Explosives

All Mining Topic Pages

Then click here

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