

# Six Sigma Steam System Management



Steam facilities are complex systems with many potential points of failure, even the smallest of which can increase cost and risk if left untended. In order to identify and improve weak points in a system, a methodology must be applied in a consistent manner.

Six Sigma, DMAIC, is a data-driven improvement cycle that is applied to business processes to achieve measurable, reproducible results. By applying Six Sigma principles, areas of cost and risk can be identified and rectified.

Six Sigma, DMAIC, is comprised of five phases: Define, Measure, Analyze, Improve and Control. When each of these phases is applied to steam system management, problems are identified, baselines are established, causes of inefficiencies are targeted, operations are improved, and optimal operating conditions become the normal state of business.

## Phase 1: Define

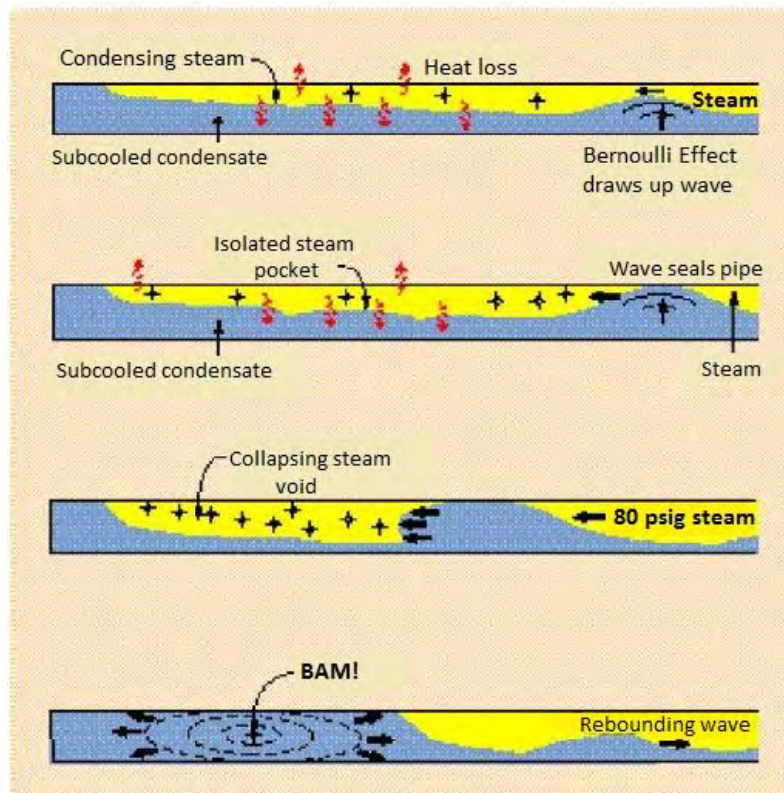
The first step in Six Sigma, DMAIC, is the Define phase. In this phase, steam system stakeholders identify problems, goals, and benefits. Resources, both available and required, are also identified at this point.

Problems in steam systems are usually caused by leaks, damage, and energy loss. An understanding of the damage these types of failures can cause is necessary to the Define phase.

**Leaks.** Leaks affect the efficient operation of equipment. Inefficient operations result in higher costs, and even small leaks can result in significant losses over time. Although cost is an important metric when justifying the expense of repairs, it is not the only concern; leaks can also endanger people, assets, and the environment. In some industries government regulations and internal policies require operators to respond to leaks, and failure to cure breakdowns can result in fines and negative public perception.

**Damage.** Damage results in inefficient operations, which are experienced in forms such as fouled exchangers, wet steam, and poor control of condensate.

Causes of damage include two phase flow, high velocity flow, and water hammer (see Figure 1).



*Figure 1: Water hammer cycle*

Two phase flow occurs when a hot stream mixes with a cold stream. In steam systems, this happens in a condensate return line as a steam trap discharges hot condensate, under pressure, to a lower pressure. The condensate temperature must drop very quickly to the boiling point of the lower pressure. The surplus heat re-evaporates a portion of the condensate into flash steam. The two phase flow is believed to occur when partially-failed steam traps allow condensate and steam to leak into the condensate header. In steam and condensate return piping, two phase flow results in frictional drop and can lead to accumulation, causing slugs of condensate, which come into contact and damage pipe support. High velocity flow damages infrastructure by causing erosion of fittings and pipes.

High velocity water flow can occur when high capacity steam traps cycle with an on/off motion discharge, in some cases creating flash steam velocity in excess of 627 ft/s (428 mph). Water hammer erodes pipes, damages pipe supports, and can cause an under-designed system to fail. It occurs when a slug forms a wave that can then travel within the piping system, causing damage when changes in direction and terrain are encountered and when pipe valves provide a restriction. This damage mechanism can be caused by incorrect trap selection, faulty steam trap operation, or poor piping design. These three mechanisms have led to line leaks at elbows (geometry changes), valve bonnet leaks, and damage to vessels at nozzle attachments (see Figure 2).



*Figure 2: Water hammer damage*

**Energy loss.** Steam costs are incurred from unrecovered condensate through additional make-up water costs and lost heat energy. Lost condensate loses its heat energy and is typically routed to a process or non-recovered drain. Lost condensate, which is filtered and demineralized or reverse osmosis water, has a cost associated with it and its heat energy.

## Phase 2: Measure

The Measure phase of Six Sigma includes the establishment of a baseline and the collection of data for analysis. In steam systems, the identification and elimination of defects in the physical system are the best method for reducing costs.

A properly functioning system with strong mechanical integrity saves costs by mitigating unexpected repairs, reducing energy loss, reducing product loss, and preventing fines and clean-up expenses. The most critical systems should be inspected on a semi-monthly basis, while routine inspections for maintenance and repair should be carried out annually. At one studied steam facility, the steam drums are state-licensed and on a 5-year internal inspection frequency. The drums are routinely inspected to find wall erosion, evidence of demister damage, and other mechanical damage.

Surveys should be conducted at a frequency based on pressure and trap population. Steam trap surveys measure lost steam as a cost to a facility to justify maintenance and repair. Trap surveys also identify failed closed traps, cold traps, and disconnected or out of service traps. The DOE (Department of Energy) and EPRI (Electric Power Research Institute) both recommend that organizations set a frequency for steam trap inspection based on the pressures of the steam, the uses of the steam, and the steam trap population number. The cost of repairing blown-through or failed open traps is justified by the return on investment based on lost steam.

Steam leak surveys are recommended as a complement to steam trap surveys. These identify steam leaks, which cause the loss of the energy of useful steam; reduce the overall reliability of the plant by making leaks an accepted part of the landscape; and create safety risks for employees. Additionally, most surveys for leaks utilize equipment that can be easily employed for other utility leaks, such as compressed air and nitrogen. Both of these are a source of potential costs to the facility that can be located and repaired during steam leak activities.

### Phase 3: Analyze

With the results of the surveys completed, the systems can be analyzed and the root cause identified. This is the third phase of Six Sigma, DMAIC.

The mechanical integrity of a system depends on proper inspection, maintenance, and flow management procedures. Particularly, leaks must be appropriately addressed and risk assessed in high pressure systems.

Different types of leaks cause different types of damage. Pipes are damaged by gasket leaks and erosions, valves are damaged by packing leaks, and vessels are damaged by gasket leaks, bad nozzles, and erosion.

Damage to piping is most often detected through wall erosion at geometry changes. This damage is most commonly seen on vessel inlets and where level control systems supply condensate to headers on condensate flash drums. This condition creates the possibility for water hammer when cool condensate mixes with warm condensate. It also creates the condition for localized high velocity that can create damaging erosion in the piping component.

Another condition that damages valves is the mixing of condensate streams and high velocity flows. This damage has been observed in gasket leaks in manual valves, which has been attributed to water hammer and from high velocity streams noted at the discharge of valves used for level control.

Water hammer impacts mechanical integrity through equipment damage. Erosion of the automated globe valves (control valves) has been observed and is best mitigated by addressing the root cause of excess velocity. Erosion damage has resulted in loss of containment issues and higher than normal wall losses as measured during routine thickness inspection as part of the site on-stream mechanical integrity program.

Vessel damage is typically associated with the same root causes of piping and valve damage: water hammer and erosion. Common vessel damage can include the loss of containment of inlet nozzles from water hammer; temperature stratification in vessels causing gasket leaks nozzles; and through-wall erosion on inlet nozzles.

A severe incident occurred in New York City when a 20-inch 180 psig steam line failed underground. New York City transports over 25 billion pounds of steam at 180 psig each year through 105 miles of underground tunnels containing steam piping. Manholes and water vapor are visible at street level. Rain enters the tunnels and sometimes submerges the lower elevations of steam piping. This flooding can increase steam condensation in the submerged pipes, leading to the accumulation of large quantities of condensate unless it is effectively removed. The flooding can also cause the formation of large water slugs that, in turn, lead to water hammer.

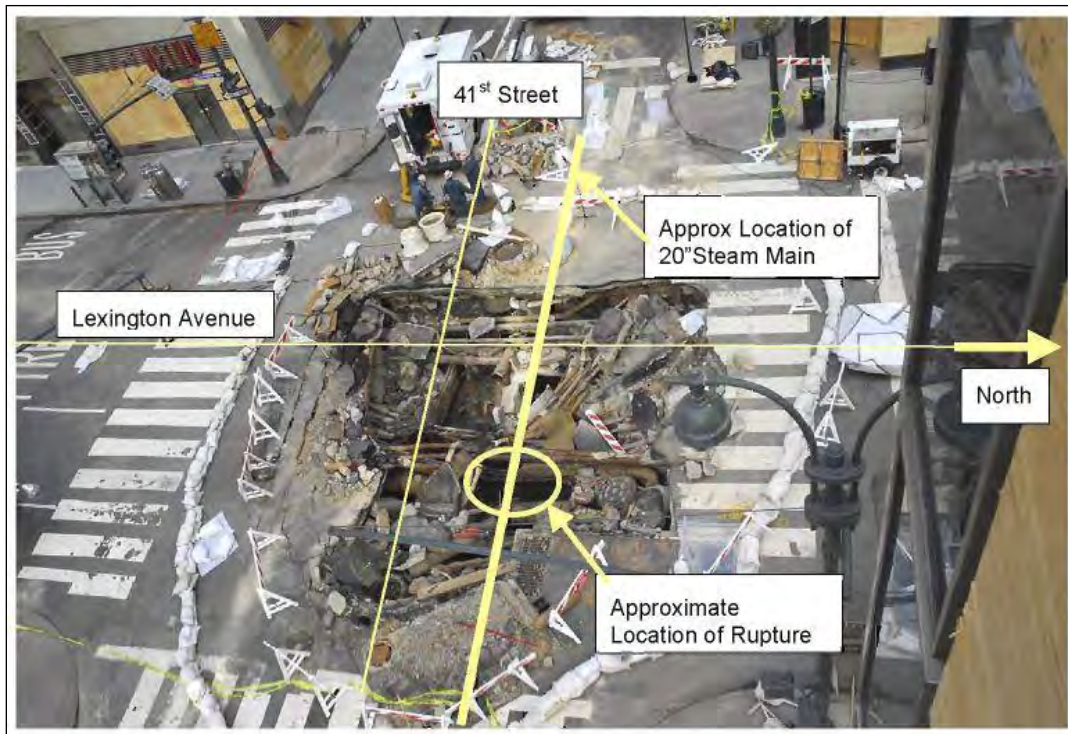


Figure 3: Water Hammer Damage

In this incident, a series of plugged steam traps allowed condensate to back up in the lower sections of the steam main. The condensate led to water hammer, which led to an explosion, and high pressure steam erupted from a large hole that had erupted in the street. The result was significant soil and civil and property damage.

## Phase 4: Improve

In the Improve phase of Six Sigma, all the previous work is put into action. Now is the time to improve the system through recommendations and changes. Risks must be assessed with regard to loss of containment and personnel exposure, as well as costs. Steps should be taken to prevent accidents, adhere to government regulations, and retain products. Facilities should implement the results of steam trap surveys as follows:

- Replace any identified failed open steam traps to prevent steam loss.
- Re-check cold and out of service traps and replace as necessary.
- Repair all steam and utility leaks.
- Replace missing and damaged insulation.
- Rework application piping to ensure optimum steam trap performance.
- Modify piping to reduce high velocity condensate that causes water hammer and erosion.
- Add blowdown and condensate recovery packages.
- Improve steam tracing efficiency.
- Improve heat exchanger operation.
- Create best practices through site specifications



<b>Trap Checking Frequency with Respect to Trap Applications</b>	
<b>Application</b>	<b>Trap-Checking Frequency</b>
All	After initial installation and/or maintenance
Steam tracing-outdoor, low pressure	At the start of seasonal use and at the coldest part of the season, not less than twice a year
Steam tracing-all others	Once a quarter with emphasis during cold periods
Steam drip and turbine drain	Major concern is condensate backup and open bypasses. Check:
Below 300 psi	Monthly
300-600 psi	Semi-monthly or Monthly
Above 600 psi	Semi-monthly
Process traps	Major concern is condensate backup and operating pressure. Check monthly.
Notes:	
<ol style="list-style-type: none"> <li>The scheduling and frequency of a checking program can be readjusted after the results have been monitored over a period of time. In nuclear power plants, ALARA considerations also influence scheduling of steam trap checking.</li> </ol>	

Areas of improvement that can reduce costs are makeup water, lost heating energy, and lost condensate.

**Makeup water.** Makeup water is water added to a steam system to compensate for water lost to leakage or evaporation. Costs associated with makeup water are raw water, treatment costs, chemical costs, resin and membranes associated with maintenance costs from operations, and technicians' costs per gallon for variable costs. Damage mechanisms related to faulty equipment or poor makeup can include water side corrosion from improper chemical or dissolved oxygen. The makeup water is normally a surface water (river or lake) source or well water (underground), with each source having costs incurred with filtration and purification. This highlights the need for proper inspection of deaerator equipment, consistent water sampling of steam systems per recommended practices, and proper online analyzer operation.

**Lost heating energy.** Poor water quality can affect heating by internally fouling heating surfaces. This fouling can lead to poor heat transfer requiring frequent cleaning. The fouling can also lead to the establishment of corrosion cells in the normally clean boiler feed water system. This can be a problem in both fired and waste heat boilers. Attention to proper blow down, inspection of systems during outages for abnormal conditions and damage, and use of time-based cleaning for establishment of passivation are recommended techniques for long term reliability.

**Lost condensate.** Lost condensate loses its heat energy, resulting in waste and, therefore, cost. Lost condensate is typically routed to a process or non-recovered drain. The steam purity and the process uses require differing levels of cleanliness. Typically, steam used to power turbines is the cleanest and has the most critical cleanliness / chemical requirements. Condensate streams blowing to grade and drains should be evaluated for return and capture to reduce makeup costs and volumes.

## Design reviews of the system

While any steps taken to repair, replace, or modify parts of a system will deliver some benefits, a full design review of the system is necessary to achieve optimal improvement. These reviews examine repeat failure locations for erosion. Once a pattern of poor reliability is observed, the areas involved in the failures should be targeted for design improvements or review in order to improve the reliability of the steam and condensate system.

For example, one studied facility has several locations where a cycling steam trap is utilized for reboiler level control. These locations have seen repeated cycling when system volume surges, resulting in erosion and damaged downstream equipment. Additionally, several level control locations feeding deaerator levels exhibited erosion, which too was suspected to be caused by high flow issues. In cases such as this, a resizing of the line or metallurgy change should be considered. Level controls in other locations have seen similar issues. These should be modified to improve the system's reliability and inherent safety when possible.



## Phase 5: Control

The Control phase of Six Sigma ensures that the work done in the previous phases is maintained through continual measurement and application of improvements.

Control of costs begins with awareness and communication. The cost of steam impacts the facility and each employee in the form of reliability, shared costs, and internal failures from root causes such as waterside corrosion and velocity-induced erosion. Such costs increase the overall plant costs and decrease the competitiveness and profitability of the facility.

Reliability costs are captured in equipment costs to repair, lost opportunity from unavailable equipment, and repetitive outages. Shared costs increase the cost of operations for the users as well, since these costs are typically an allocation to all users.

A unit or site becomes more competitive when it is able to reduce operational costs, which can only be achieved by constant vigilance. The reporting of all deficiencies and issues within the facility ensures proper investigation and recording for follow-up. Poor reliability and operation of equipment needs to be documented to build history and costs associated with operation of equipment that is less than adequate, and tracking mechanisms must be in place to guide budgeting decisions for continuing elimination of root causes and design improvements to correct defects.



Mechanical integrity practices and improvements include a raised awareness of steam issues, which should lead to a review of piping design for systems experiencing accelerated erosion and water hammer for root cause analysis. An increased focus on velocity issues and erosion elimination must also be developed, and all personnel involved in the operations, maintenance, and management of the facility must be informed about how to highlight maintenance and properly prioritize asset care.

## Conclusion

System optimization is an important metric for energy and defect detection. As more plants focus on better efficiency and integration, the importance of sustainable system maintenance and design review is greater.

The working of a maintenance program represents the partnership between the site operations experts and steam trap experts. A partnership allows opportunities to be discovered and solutions to be provided for continued efficiency and reliability. In order to achieve optimization, steam system facilities must:

- Conduct a review of systems throughout a facility
- Standardize component replacement to reduce field work and expedite repairs
- Eliminate threaded connections at sites, except for universal connectors
- Reduce warehouse inventory through standardization
- Move the focus on failures to a focus on reliability and leveraging defect elimination with vendors
- Set up automated preventative maintenance plans for sustainability, including inspections, surveys, and design reviews and improvements

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