Four Strategies to Minimize the Cost of a Piping Thermal Maintenance System Without Compromising Performance

Brandon Forbes, PE
AMETEK/Controls Southeast, Inc.
July 14, 2020

Introduction

Where the process fluid must be maintained within a certain operating temperature window, the piping will likely require the application of a **thermal maintenance system**. Thermal maintenance systems can utilize a broad range of technologies from bare tube tracing to fully jacketed pipe. However, regardless of the technology employed, engineering must be performed to design the system. The approach used for the engineering and design of the system can have a dramatic impact on the cost. **This paper presents four strategies for minimizing the total cost without compromising performance.** The strategies are:

1. Match the heating technology to the application
2. Optimize the heating circuit lengths
3. Optimize the utility infrastructure
4. Structure the bid process to reward optimization

Additionally, three real-life examples are presented that demonstrate the actual savings that these strategies can achieve. These examples are:

- Example A showing the benefit of Strategies 1 and 2 combined
- Example B showing the benefit of Strategy 3
- Example C showing the benefit of Strategy 4

While much of this discussion centers around steam heating systems, the same principles apply to other heating fluids and cooling systems.

Strategy 1 – Match the Heating Technology to the Application

Different processes require different considerations in the design of the thermal maintenance system. The most common considerations are:

- **The purpose of the heating system:** Liquids must often be maintained above a freezing point. However, for vapors, condensation within the piping is often a primary concern. In some applications, a pre-heat or recovery (melt-out) condition is the primary concern.
- **The acceptable temperature window:** Some processes must simply be maintained above or below a critical threshold. Other processes have both an upper and lower bound that must be considered.
- **The available temperature differential:** Some applications afford a large "temperature delta" that enables even a relatively poor performing technology to be used successfully (e.g. maintaining a pipe above the water freezing point (0°C) using 10 barg steam (184°C)). Other applications provide very little "temperature delta" and require a very robust heating system to assure success (e.g. maintaining a pipe at 180°C using the same (184°C) steam).

Properly matching the heating technology to the application is key to reducing cost. An “over performing” heating technology will cost more than a “performance-matched” technology. Conversely, applying an “under-performing” technology will necessitate the use of additional tracing runs and heating circuits, which will drive up the cost of the utility components. Properly matching technology will optimize both costs: (1) The heating technology itself will cost no more than what is necessary to achieve the purpose. (2) The utility infrastructure requirements will be minimized along with associated costs.

There are many tracing technology options available on the market. A true technology partner can help you select the best option without bias to any one solution. Below is one example of a robust range of heating technologies:

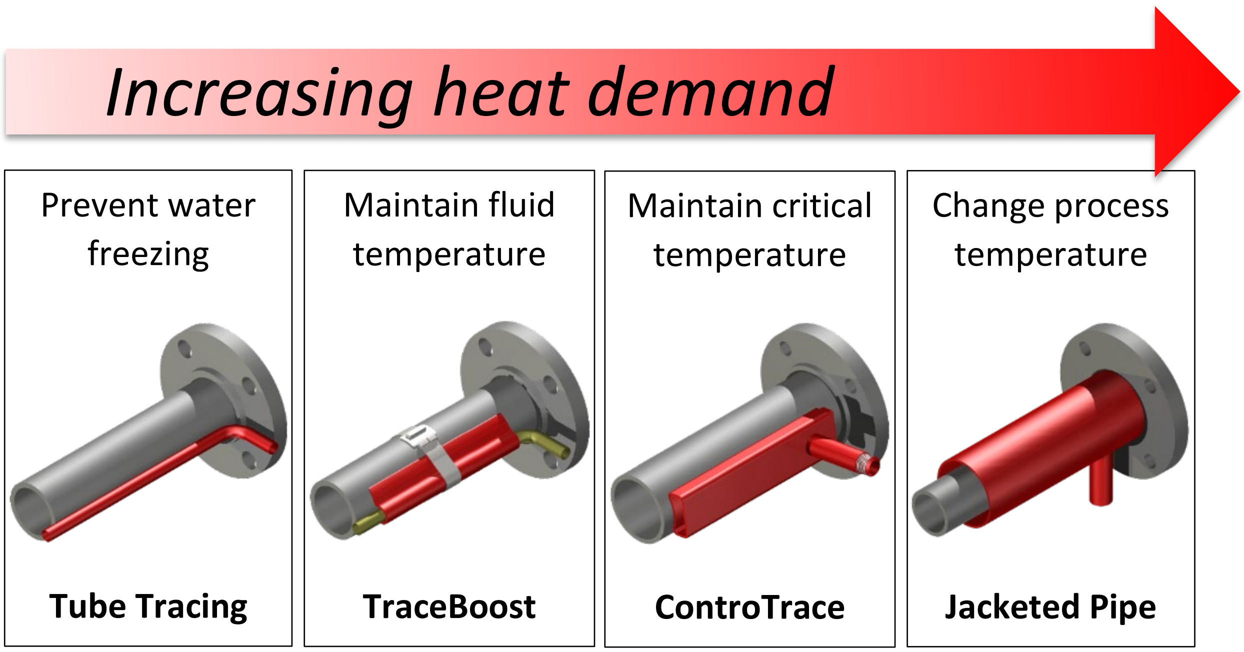

Figure 1: Heating Technology Suite Offered by CSI

Referencing the example in Figure 1: TraceBoost provides an 8x increase in heat transfer over tube tracing. ControTrace provides a 2x increase over TraceBoost as well as more consistent performance for critical applications. Jacketed Pipe has no contact resistance, therefore heat transfer is limited primarily by the convection coefficients of the fluids.

Strategy 2 – Optimize the Heating Circuit Lengths

Properly matching the heating technology to the application is only the first step. To keep costs as low as possible, the heating technology must be used to its fullest potential. Correctly sizing the system in terms of the number of tracer runs per pipe length is the most obvious aspect of this. However, it is equally important to maximize the length of heated piping between each supply and return point. Each of these heating fluid flow paths are commonly referred to as circuits.

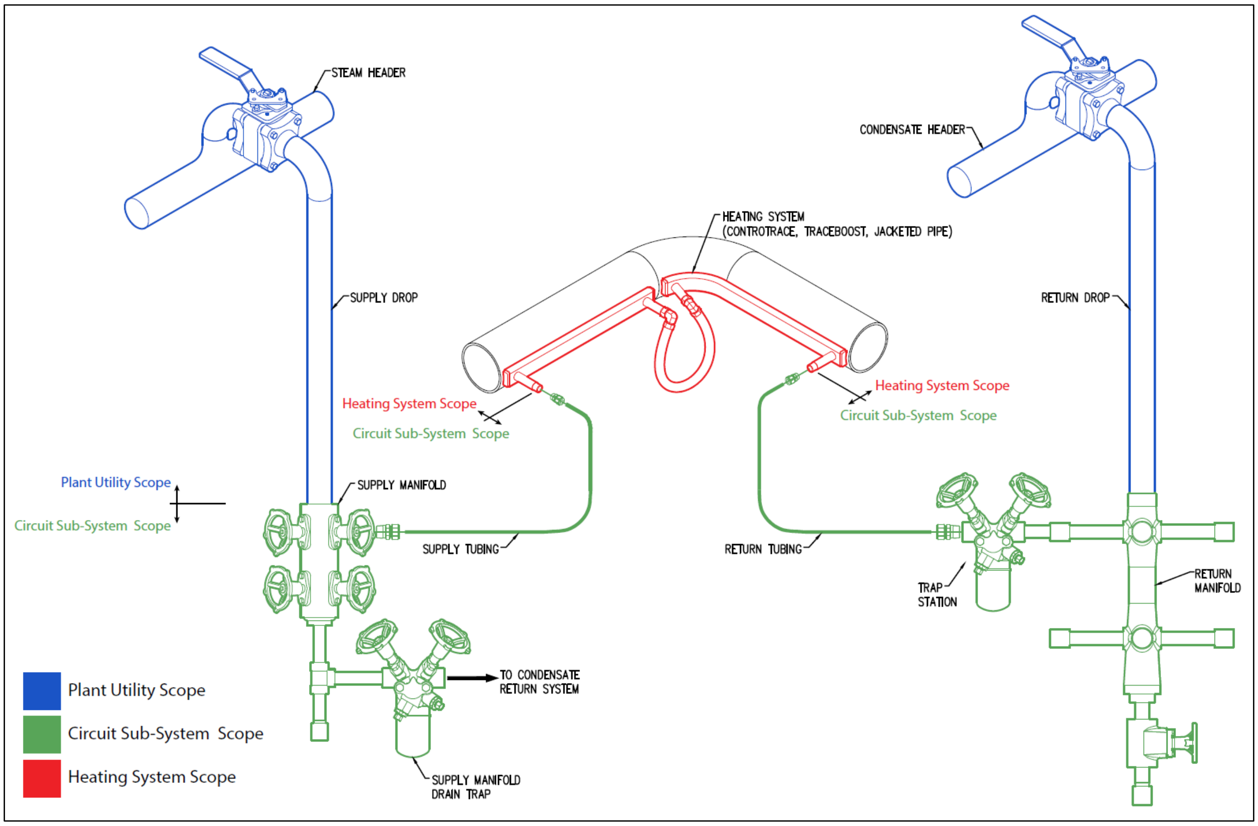

Figure 2: Components of a steam tracing circuit

The heating fluid loses temperature as it travels through the circuit. In the case of steam, the temperature loss is driven by pressure drop. If a circuit is too long, the heating fluid temperature towards the end will be too low to accomplish the thermal objective. One approach to avoid this issue is to conservatively limit the length of all the circuits. This approach is commonly the basis of plant tracing specification documents; and is also often employed by tracing vendors to avoid the burden of additional engineering. This approach works because there are no technical concerns with having a circuit that is “too short.” However, it does require an unnecessarily high number of heating circuits, which then requires additional utility infrastructure as well as the associated cost.

A preferred approach is to establish each circuit length based on an actual calculated temperature drop. At a minimum, this calculation must be performed for each unique combination of process condition and lines size. Performing this calculation will create additional engineering cost, but that cost is more than offset by the savings achieved by using a reduced utility infrastructure. In many cases, plant tracing specifications are so conservative that using calculated circuit lengths can reduce the number of circuits fourfold.

Strategy 3 – Optimize the Utility Infrastructure

Any heating system applied to piping requires periodic supply and return points. The location of these points is governed by piping geometry and the circuit length limitations. The resulting system will have supply and return points scattered throughout the facility. Proximate supply and return points are typically grouped together and connected to common supply/return manifolds.

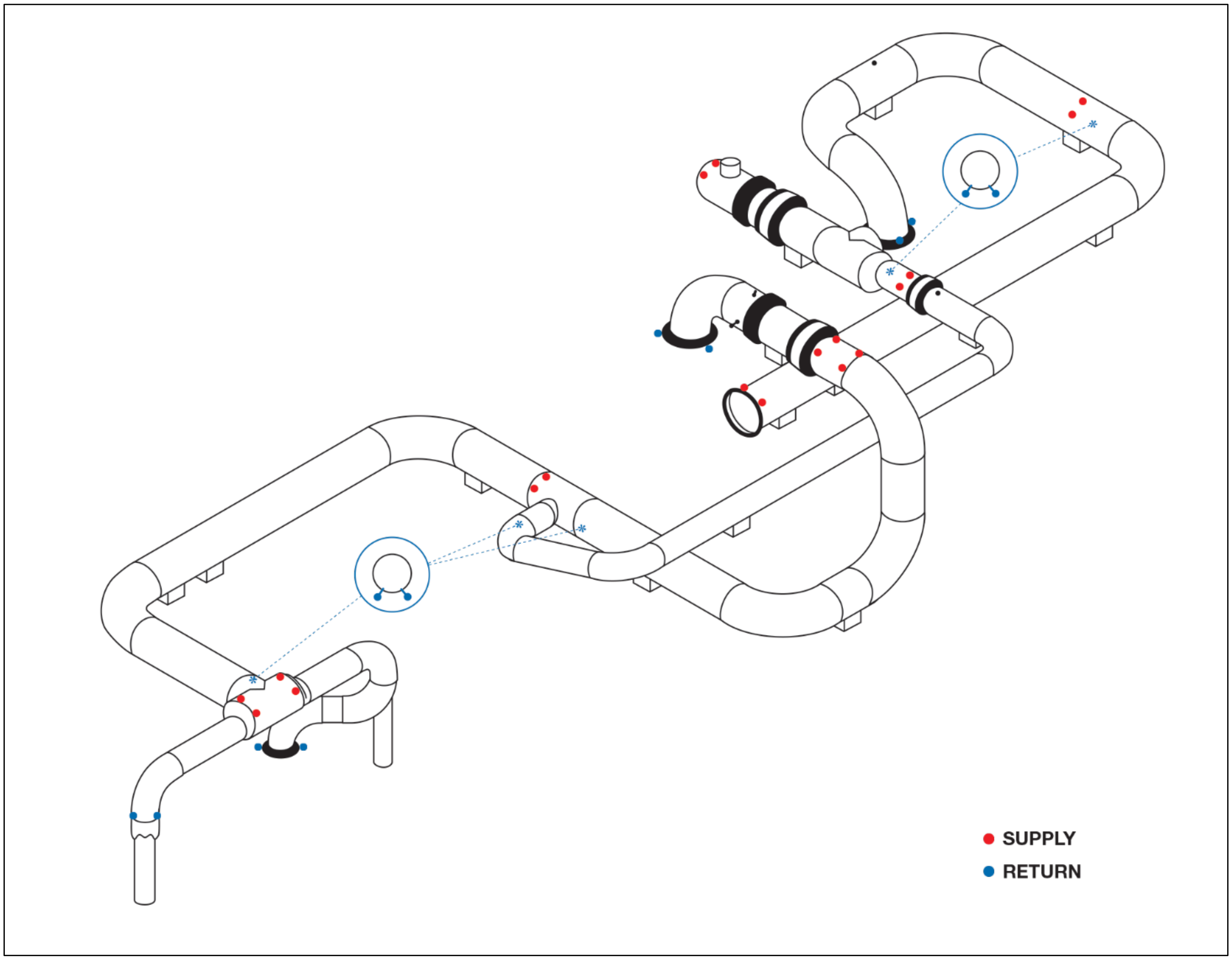

Figure 3: Example piping system with circuit supply and return points

Each manifold must be mounted at an accessible location and plumbed into the plant's supply/return headers. The total cost of each manifold is significant, which is why it is desirable to keep the total number to only what is required. However, accomplishing this practically is a challenge. The hundreds of supply/return points and thousands of possible manifold locations form a jigsaw puzzle with millions of possible solutions.

The traditional approach is to scatter manifolds throughout the plant based on rough approximations and past experiences. The heating system supply/return points are then tied in wherever they can be. Where they cannot be tied in, last-minute manifold additions become necessary. Similarly, where manifolds or ports are not needed, the paid-for hardware sits unused.

A better approach is to match the manifolds to the circuits during placement. The goal of this approach is to minimize the number of manifolds by maximizing the number of circuits connected to each manifold. For example, CSI has developed a proprietary algorithm called the Manifold Optimization Scheme (MOS). MOS analyzes the supply and return points in 3D space and determines the optimum manifold locations that result in the smallest total number of manifolds.

This tool gives customers full flexibility to restrict the analysis to only acceptable manifold locations, to restrict the supply and return tubing length, and to include existing manifolds in the analysis. With this tool, the resulting system design will always be the most optimal manifold placement solution.

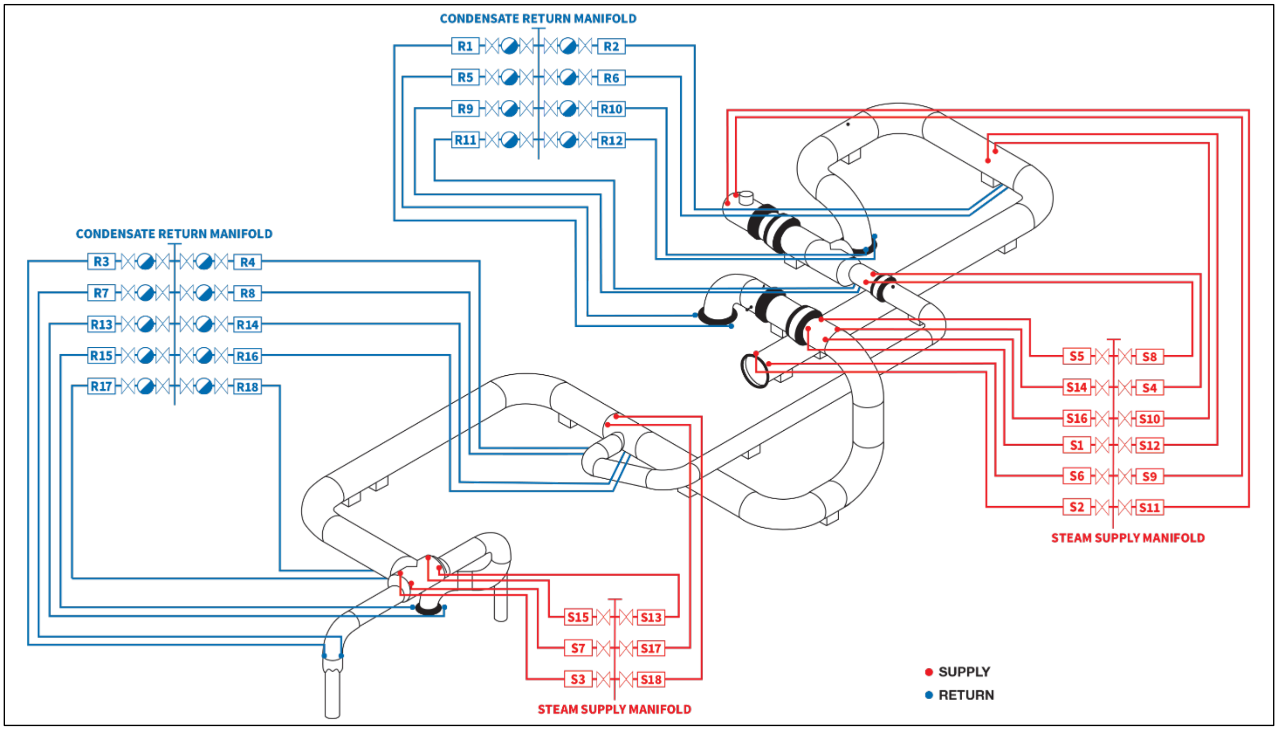

Figure 4: Example piping system with one possible manifold grouping indicated

The manifolds shown above are the most common in steam heating systems. They are less common when the heating fluid is a liquid. Nevertheless, many of the same concepts of optimization can apply regardless of the specific supply and return hardware used.

Strategy 4 – Structure the Bid Process to Reward Optimization

The most powerful tool that can be used to control costs and optimize system design is to structure the contracts, so these goals are rewarded. For example, in the case of a pipe heating system, the contract should reward the application of the three optimization strategies described above. Two commercial mechanisms should be considered to accomplish this:

1) Require Lump -Sum Bids

When a vendor is contracted to supply components at a per-unit rate, the vendor is not motivated to reduce the provided hardware quantity. Instead, vendors should be required to provide lump-sum bids that clearly define deliverables and performance guarantees. This motivates the vendor to minimize the quantities of hardware provided to maximize their profit. Of course, this approach will only be successful if the bid includes a commitment to well-defined deliverables and performance criteria. For pipe heating systems and associated hardware, consider requiring the vendor to supply the following:

- Clear statement of thermal objective for each line (for performance accountability)
- Calculations / thermal models justifying the quantity of tracers applied
- Calculations / thermal models justifying the tracer circuit lengths specified
- Detailed installation drawings for the tracing system and other supplied hardware
- Field support for and inspection of the installation
- Performance guarantee with defined corrective action
- Material specification and fabrication standards for all supplied hardware

2) Consolidate Scope to a Small Number of Vendors

A vendor can only optimize what is within their scope. They do not necessarily have good insight into how decisions about their scope affect others. One vendor's choice to optimize their scope may necessitate a disproportionate increase in another. A common example is tracing circuit lengths. The tracing vendor may be able to reduce their cost by using fewer tracer runs on the pipe by using very short circuit lengths. This can easily drive up the number of circuits, resulting in a disproportionate increase in the cost of the utility infrastructure.

The solution is to consolidate the scope of supply to a smaller number of vendors. When one entity is responsible for the total scope, optimization decisions are made with consideration for the complete system. Similar to the first strategy above, this approach is most successful when coupled with accountability to provide well-defined deliverables.

Cost Savings

The savings achieved by these four strategies can be broadly categorized into three buckets:

1. **Savings achieved by reducing the quantity of hardware.** Applying the engineered approach instead of conservative specifications will significantly reduce the number of parts required. This reduction is far more significant than any bulk buy or discount pricing effect could achieve.
2. **Savings achieved by reducing the number of last-minute purchases and project delays.** The impact of this is much more difficult to quantify, but experience shows it to be significant. A project that is well planned prior to execution experiences fewer delays and surprises.
3. **Savings achieved by reducing the long-term operating costs.** Long=term operating costs are primarily associated with energy utilization and parts replacement. Reducing the number of parts that comprise the heating system has a significant effect on both.

Example A – Optimizing Technology Selection and Circuit Lengths (Strategies 1 and 2)

CSI provided a heating system for a large, newly constructed, Canadian chemical plant. The plant design was similar to a previous plant that exclusively used bare tube tracing. It was initially expected that the same would be used in the new plant. CSI reviewed the basis of the technology selection and recommended two cost-saving changes:

1. Use ControTrace instead of tube tracing on lines with more stringent thermal requirements (lines requiring a large number of tube tracing runs)

2. Establish circuit lengths based on calculated steam pressure drop instead of the previous plant specification.

Applying these recommendations resulted in an 89% reduction in the number of steam circuits.

	Original Design Basis - Bare Tube Tracing Only	**Revised Design** - Combination of Bare Tube Tracing and ControTrace
Total Length of Pipe:	7,853 ft	7,853 ft
Total Length of Tracing:	96,351 ft	11,482 ft
Total Number of Circuits:	2,600	274

Switching a portion of the project to ControTrace increased the cost of the heating system but significantly reduced the number of circuits, providing an overall cost savings of 78%.

	Original Design Basis	**Revised Design**
Cost of Heating System:	$1,342,000	$2,073,000
Cost of Heating System Install:	$589,000	$206,000
Cost of Utility Infrastructure:	$16,105,000	$1,973,000
Cost of Utility Install:	$7,731,000	$1,223,000
Total Cost:	**$25,193,000**	**$5,475,000**

The “utility infrastructure,” shown in the above table, includes the following components:

- Steam supply manifolds and condensate return manifolds
- Supply and return tubing for each circuit (tubing connecting steam supply/return manifolds to circuit supply/return points)
- Steam trap for each circuit
- Steam trap for each supply manifold
- Fittings and hardware required to connect all the above components

Note that in this example, the TraceBoost-enhanced tube tracing could have also been used as an intermediate technology between the tube trancing and the ControTrace. Doing so would have resulted in additional cost savings. However, the customer chose not to pursue this option as they preferred the simplicity of using a smaller number of technologies.

Additional utility infrastructure also creates additional operating expenses. These expenses take the form of additional steam consumption to support the extra heat load, and the form of additional maintenance cost to maintain the traps.

	Original Design Basis	**Revised Design**
Heating System Steam Load:	8,600 lb/hr	8,600 lb/hr
Utility Infrastructure Steam Load:	53,500 lb/hr	5,200 lb/hr
Total Steam Load:	62,100 lb/hr	13,800 lb/hr

Yearly Steam Cost:	**$4,352,000**	**$967,000**

	Original Design Basis	Revised Design
Number of Circuits:	2,600	274
Trap replacements / year:	433	46
Yearly Trap Cost:	**$507,000**	**$53,000**

The cost basis of this project's individual items is summarized below. Note that this project utilized high pressure steam, which required more expensive manifolds and steam traps. A more typical steam pressure would have resulted in lower utility infrastructure costs and lower operating costs for both options. The impact of this change on purchase cost would be relatively small with savings shifting from 78%, as shown above, to roughly 76%. The impact on operating cost would be more significant, with yearly savings shifting from $3.4 million to $2.1 million for steam cost and $454,000 to $175,000 for trap maintenance.

Item	Cost
12 Port High Pressure Supply Manifold	$7,270.10 each
½" Tubing x NPT Adapter	$15.65 each
½" Tubing x JIC Adapter	$37.05 each
Tubing End Seal Kit	$52.95 each
½" Stainless Pre-Insulated Tubing	$7.18 / ft
½" Tubing x Tubing Union	$34.65 each
12 Port High Pressure Return Manifold	$28,619.46 each
½" Stainless Tracer Tubing	$1.75 / ft
Labor Rate	$50.00 / hr
Steam	$8.00 / 1,000 lb
Replacement High Pressure Steam Trap	$1,120.00 each
Steam Trap Service Life	6 Years

Note that this and the following examples all use pre-insulated tubing to supply and return the heating fluid to the tracing. Pre-insulated tubing typically has a higher purchase cost than traditional hard pipe, but it provides significant time savings during installation.

Example B – Optimizing Utility Infrastructure (Strategy 3)

CSI provided a heating system for a major Middle Eastern refinery expansion project. The EPC had already placed manifolds throughout the plant before CSI was engaged on the project. CSI was asked to optimize the manifold utilization and applied MOS to do so. The expectation was that some portion of the planned manifolds would prove unnecessary and could be removed from the plan. This expectation proved to be true; optimization resulted in the removal of 15% of the manifolds and a total cost reduction of 43%.

	Planned	Optimized
Number of Manifolds:	186	159
Number of Used Ports:	1,116	762
Total Length of Tubing (ft):	225,000	80,000
Total Cost:	**$3,187,000**	**$1,820,000**

While the cost savings shown above are significant, employing MOS on most projects will yield even more significant savings. Two factors affecting this project that limited the cost savings potential were:

1. The planned manifold locations were based on a previous project for a very similar plant utilizing the same heating technology. Thus, the planned locations were actually very good approximations of what would be needed, much better than on an average project.
2. Only manifold locations that were already planned could be used. CSI was engaged late in the project cycle. Planned manifolds could be eliminated, but adding manifold locations was not an option. Thus, the resulting manifold locations were not optimized to the extent that they could have been.

The cost basis of this project's individual items is summarized below. ¾" tubing is used for each circuit supply run; ½" tubing is used for each circuit return run.

Item	Cost	
4 Port Supply Manifold	$2,540.82	each
8 Port Supply Manifold	$3,787.26	each
12 Port Supply Manifold	$5,250.84	each
4 Port Return Manifold	$948.93	each
8 Port Return Manifold	$1,731.48	each
12 Port Return Manifold	$2,499.93	each
Trap station with Steam Trap	$964.44	each
¾" Stainless Steel Pre-Insulated Tubing	$6.56	/ ft
½" Stainless Steel Pre-Insulated Tubing	$4.69	/ ft
¾" Tubing x NPT Adapter	$32.67	each
¾" Tubing Union	$55.22	each
¾" Tubing x JIC Adapter	$69.67	each
½" Tubing x ¾" NPT Adapter	$27.36	each
½" Tubing Union	$33.97	each
½" Tubing x ¾" JIC Adapter	$55.78	each

Example C – Optimizing the Bid Structure (Strategy 4)

CSI provided a bid for another major Middle Eastern refinery expansion project. This bid included the application of all three optimization strategies discussed above:

1. Optimization of technology by using a combination of tube tracing and TraceBoost in place of tube tracing alone.
2. Optimization of circuit lengths via engineering calculations
3. Optimization of manifold quantity and placement via the MOS algorithm

CSI's lump-sum bid was being compared to another vendor's per-unit bid. The end user chose to use the other vendor due to the lower apparent per-unit cost and the relatively late engagement with CSI. After the project completion, CSI was provided with a tabulation of the actual hardware used on the project. Unsurprisingly, although the project scope had not increased, the number of components used was considerably higher than what was initially estimated. The final cost of the as-built system far exceeded CSI's lump-sum proposal.

	As-Built System (unit pricing)	CSI Proposed System (lump sum)
Engineering:	-	$35,010
Tracing System:	$1,075,801	$786,814
Manifolds + Traps + Valves:	$7,138,942	$2,925,358
S/R Tubing + Adapters:	$3,399,362	$1,812,481
Installation Labor:	$6,370,765	$3,504,970
Total cost:	**$17,984,870**	**$9,064,633**

The per-unit pricing created a motivation for the vendor to allow the project scope to balloon. A lump-sum bid would have ensured that costs increase only in response to a legitimate expansion of scope. By using the lump-sum approach, the end user could have saved 50% on the project.

The cost basis of this project's individual items is summarized below. The as-built system utilized a combination of 3/8", 1/2", and 3/4" tube tracing. The optimized system utilized a combination of 1/2" tube tracing and 1/2" TraceBoost.

Description	Cost
3/8" Stainless Steel Tracer Tubing	$2.76 / ft
1/2" Stainless Steel Tracer Tubing	$3.34 / ft
3/4" Stainless Steel Tracer Tubing	$6.65 / ft
TraceBOOST Enhancer	$7.19 / ft
3/8" Tubing Union	$13.71 each
3/8" Tubing x 3/4" SW Adapter	$19.42 each
3/8" x 1/2" Tubing Union	$21.04 each
1/2" Tubing Union	$20.42 each
1/2" Tubing x 3/4" SW Adapter	$21.99 each
1/2" Tubing x NPT Adapter	$27.89 each
3/4" Tubing Union	$32.99 each
3/4" Tubing x SW Adapter	$24.93 each
3/4" Nipple	$9.24 each
Tracer Banding	$0.49 / ft
Tracer Banding Buckles	$0.42 each
Heat Transfer Compound	$61.60 / gal
4 Port Return Manifold	$1,627.78 each
8 Port Return Manifold	$2,220.68 each
12 Port Return Manifold	$2,887.50 each
4 Port Supply Manifold	$2,962.96 each

Description	Cost	
8 Port Supply Manifold	$4,288.90	each
12 Port Supply Manifold	$5,824.28	each
1/2" Plug	$8.78	each
3/8" Stainless Steel Pre-Insulated Tubing	$4.90	/ ft
1/2" Stainless Steel Pre-Insulated Tubing	$4.69	/ ft
3/4" Stainless Steel Pre-Insulated Tubing	$6.56	/ ft
Pre-Insulated Tubing End Seal	$7.64	each
3/4" Circuit Isolation Valve	$115.50	each
Steam Trap	$934.78	each

Conclusion

Controlling the cost of a thermal maintenance system requires the vendors to apply an engineered approach. The key focus of this engineering approach is to:

1. Match the heating technology to the application
2. Optimize the heating circuit lengths
3. Optimize the utility infrastructure

In order to assure that the vendor(s) applies this approach, the bid should be structured in such a way that optimization is rewarded. This is accomplished by:

1. Require lump-sum bids with well-defined deliverables and performance criteria
2. Consolidate the scope to a smaller number of vendors to achieve cross-discipline optimization

To best capitalize on the above strategies, look for a technology-neutral thermal maintenance system provider with strong engineering capabilities.