

Enhancing the efficiency of sprinkler system planning and installation with a focus on cost-effectiveness.

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Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: *Charlotte E Stroud*

Date: 19.05.24

Acknowledgements

“Do your best”.

Engrained in me from a young age, I was always told that if I did my best, it was good enough.

I cannot thank my amazing parents, Kevin, and Joanne, for their constant encouragement, support and for always being proud of the person I grew to become, under the invaluable shaping of them both - inspiring me to be the best version of myself, always.

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Abstract

This project aimed to enhance the efficiency of sprinkler system planning and installation with a focus on cost-effectiveness, addressing a notable 8-12% reduction in profit margins from recent jobs. Methodologies employed included a comprehensive literature review, process representative interviews, and the application of DMAIC and 5S methodologies. The literature review identified the Darcy-Weisbach formula as a superior choice for calculating friction loss in pipe systems over the Hazen-Williams formula, due to its accuracy under varying conditions. Advanced software tools were updated to incorporate this formula, optimizing system design and installation processes.

Data collection involved interviewing department representatives and shadowing processes, which highlighted key areas for improvement in communication and process clarity. These insights led to the reworking of tender proposals to enhance design efficiency and project execution. Beta testing of these changes confirmed their effectiveness, demonstrating cost reductions through the use of smaller pipe diameters while maintaining compliance and performance standards.

The successful beta testing indicated that the updated FireCAD software and revised tender documents achieved the project's objectives. Further work suggests annual testing to ensure continued efficiency and adherence to best practices. Additionally, ongoing professional development and training for personnel, as well as bi-annual reviews, are recommended to maintain process improvements and sustain desired profit margins and operational excellence.

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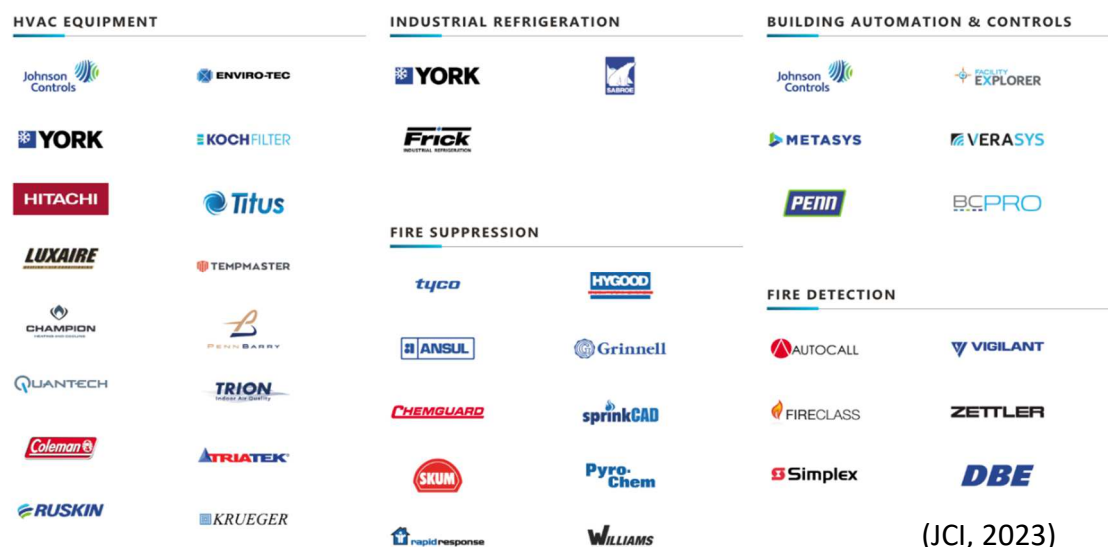
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Johnson Controls

Johnson Controls Int Plc is an American/Irish multinational organisation based in Cork, Ireland, producing fire, HVAC and security systems and equipment for buildings. They're a self-claimed world leader in creating smart buildings, safe and healthy sustainable spaces, dubbing themselves as the company with 'the largest portfolio of building technology, software and services' to offer (JCI, 2023).

They are the world's largest manufacturer of automotive batteries, including the large names as Autozone, Costco and Ford, and recently underwent a relaunch under the new brand, Clarion, where they continue to dominate the field of automotive battery providers.

Founded in 1885 by Warren Johnson as a simple electrical temperature regulation enterprise, Johnson Controls Plc has experienced remarkable growth over the years, known for the acquisition of any competitors. Evolving into a multi-billion-dollar company that spans various sectors very popular in the construction industry, with its current estimated value is \$38 billion USD. (Forbes, 2023)



Following the acquisition of Tyco, global leader in fire suppression and security, JCI ascended to become the 14th largest industrial company in the US market by capitalization (Forbes, 2016). Tyco are renowned for their fire protection component manufacturing, but it is their team of excellent fire suppression system designer that make the company one of a small number of level 4 accredited companies in the UK, proving their advantage as one of the top global industrial companies worldwide.

I - Introduction

I.I - Problem Statement

Whilst nationally recognised as a great team of designers, the internal budget reports would tell a different story. Struggling to keep costs associated with the design and installation of sprinkler systems down, JCI need a more economical and efficient way to work, in terms of producing systems, validifying and installing it from a cost focused perspective.

Findings from the 2022 Q2 financial report determined that, excluding the years affected by the global COVID-19 pandemic, there has been a continued struggle on profit of similar jobs. The findings reported and summarised by the financial analysis team concluded that the fire suppression sector was making a reduced profit of 11% average of jobs over ten million pounds, and 7% average on jobs over one million pounds, instead of previous 23% and 13% averages respectively.

Comprehensive cost analysis revealed that the issue stems from the time allocated to design, redesign, and hydraulic analysis in major projects. Since these stages are essential and cannot be eliminated to cut costs, identifying areas for savings necessitates a thorough investigation across all teams. This inquiry should also consider external factors such as installation expenses, supply costs, and delay-related expenditures.

I.II - Project Objectives

This project aims to review the current process of the design through to installation of a sprinkler system within the procurement, design, and operations departments of our major projects group division (MPG). Reviewing the current process, we will determine the efficiency and devise any alternative methods or processes in which time and therefore money is saved, optimising the process to maximise financial profit.

We aim to gain a full understanding of the hydraulic package to analyse and find any correlation which can impact the time and costly factors of designing and calculating a compliant sprinkler system. Through the hydraulic package analysis, verification of valid and modern calculations can be undertaken, to identify the cause of oversized pipes being used.

To be able to conduct the review and devise a plan to overcome the difficulties, we require the full cooperation of all subdivisions of the DCOE's Fire Suppression, all Major projects departments, procurement, design, and operations. Entire transparency from all included in the review is required to ensure the findings to determine the efficiency of the current process, are an accurate representation. This is the only way of determining the appropriate areas of improvement required for achieving the goals outlined.

I.III - Plan

The project aims to review the entire fire suppression system design and installation process, identifying time and budget constraints through data collection and analysis. This includes reviewing departmental processes, analysing data from previous contracts, and evaluating hydraulic packages.

Performance reviews of all stages of the design team will ensure optimal and cost-effective component selection, determined through performance vs cost analysis. Each department will be consulted for input and improvement suggestions, with potential testing of recommendations. Techniques for performance reviews include active listening and semi-structured interviews to ensure topic maintenance, whilst allowing the review to be tailored to the interviewee's responses.

Analysis consistently shows hydraulic preference for smaller pipes, but cost considerations may vary. Ensuring current and accurate cost figures from external contractors is crucial. Collaboration with subcontractors will ensure accuracy in procurement stages, ultimately reducing any possibility of overspending due to discrepancies in procurement component costing, to actual costing.

Cost investigation of pipework installation will inform pipework selection, considering factors like trace, heating, and lagging. All parties involved, from procurement to design engineers to site teams, will understand and implement the most cost-effective solutions, preventing under-costing and overspending. Techniques like DMAIC (Define, Measure, Analyse, Improve, and Control) and the 5S (sort, Set in Order, Shine, Standardize, and Sustain) methodology will aid in analysis and improvement, alongside regression analysis and statistical analysis.



(McGab, 2024)

Figure 1 - DMAIC illustration



(Deepak, 2024)

Figure 2 - 5S Method illustration.

I.III.I – Timeline and Gantt chart

For topic maintenance, the plan includes a timeline (figure 3) and Gantt chart for visual representation, detailing tasks and tracking project progress for adherence to schedule, essential for identifying scheduling issues.

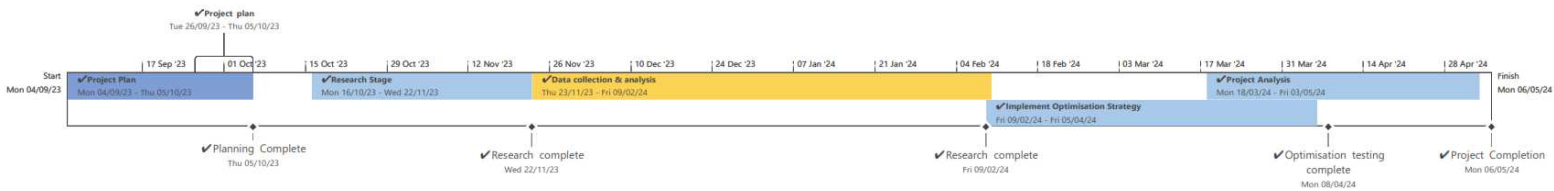


Figure 3 - timeline of projected timescale for project completion.

The Gantt chart (figure 4) illustrates the timeline in which the full investigation and report will take place, with each stage of the process having a dedicated time frame, with allowances of room for overrunning considered, summarised as seen in the project timeline below.

Overlapping tasks are scheduled to reduce timescale of the project, for example, the analysis of data coinciding with the data collections projected timeline. Advantageously, data collection is a background task, enabling a focus on data analysis to be reviewed on data collected so far. Refer to Gantt chart, figure 4 for accurate timelines and project milestone dates. The Gantt chart provides clear marked dates and task breakdowns to enable a full understanding, quickly.

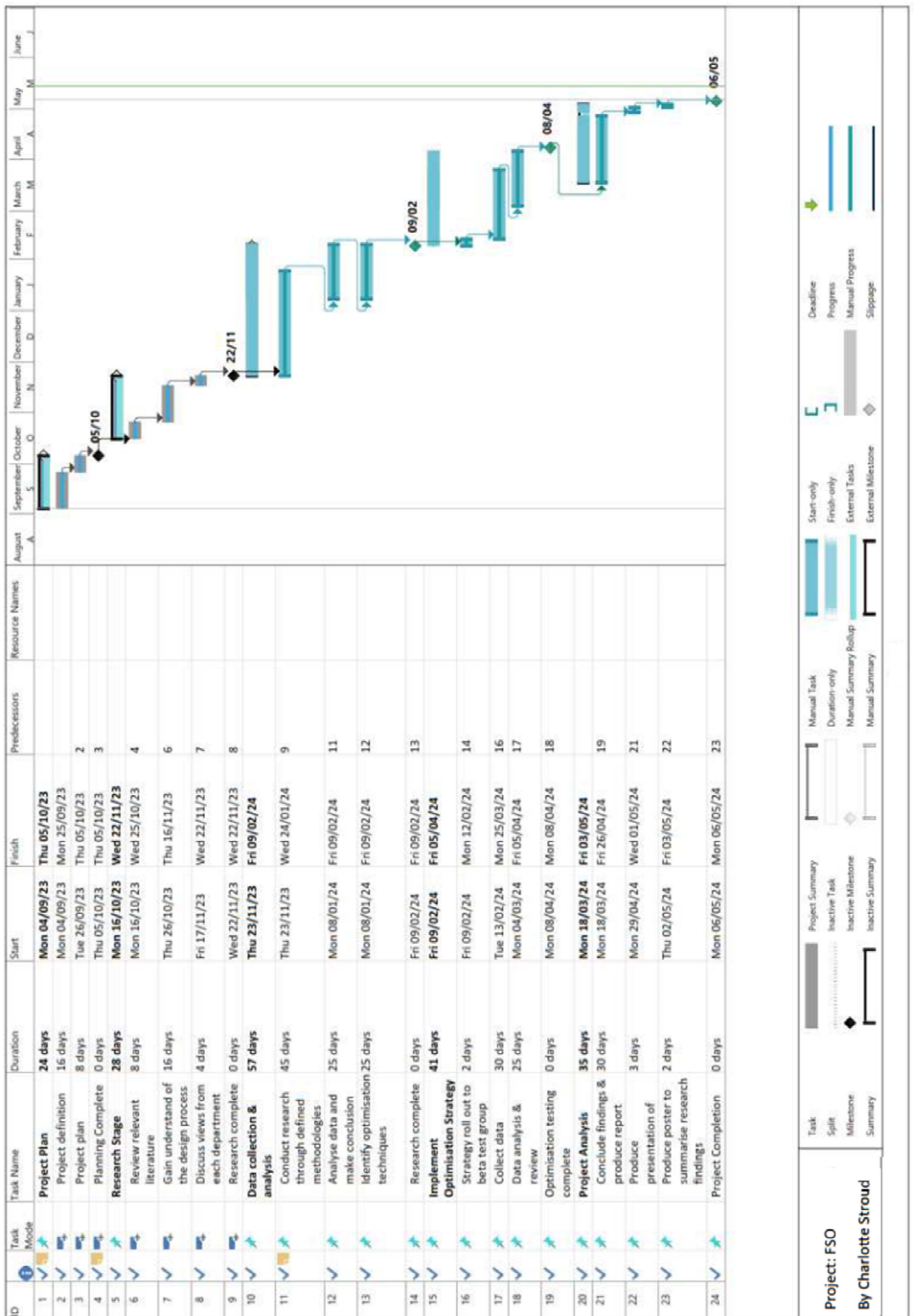


Figure 4 Project Gantt chart.

II - Literature Review

II.I - The History of Sprinkler Systems

The topic and contents of Fire Sprinkler Systems have been well explored, for over 200 years.

Sprinkler systems have been around for centuries, the first recorded was a system designed by da Vinci in the 15th Century, reported by (Murphey, 2019). A system designed to extinguish a fire in the process of food transportation in his new oven, the system was designed using buckets of water and not automatic like the systems used today. It wasn't until 1723 that sprinklers were semi-automatic, with Ambrose Godfrey implementing his design of gunpowder to trigger the release of the water (Godfrey, 1724). In 1812 William Congreve, English playwright, detailed in (Wyatt, 1813) designed the world's first recognised system in a theatre on London's Drury Lane, where a remote signal triggered punctured sprinkler pipes, producing the first spray pattern.

Designs similar to Congreves were implemented in industrial buildings across North and South America, until the automated sprinkler head development by Philip W. Pratt in 1860, and later patented in 1872. Making advancements on Pratts design, Henry S Parmalee created what is known as the first practical automated fire sprinkler head (United States of America Patent No. US154176A, 1974). The fire sprinklers holes, sealed by solder would melt from the heat of a fire, breaking the seal and dispersing water, extinguishing the fire, the very system he designed, he installed above his own piano factory (Parker, 2016).

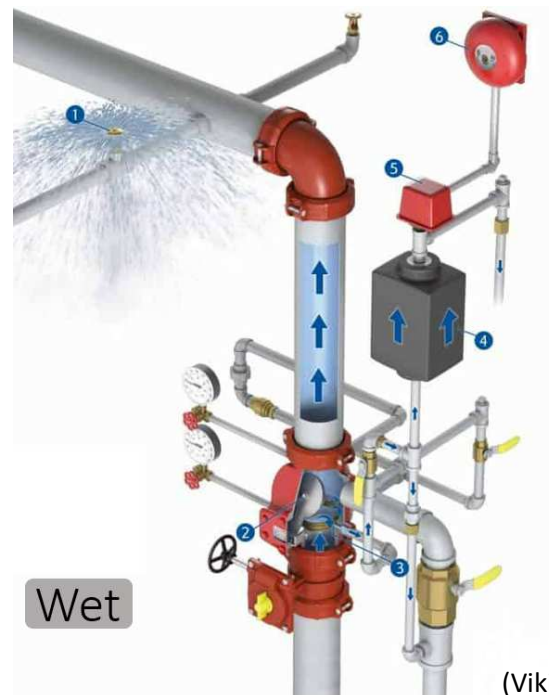
Combinations of the two greatest breakthroughs contributed to the theories used to say in the near perfect sprinkler systems across the world. Automation of the soldered outlets, for the latest designs on sprinkler heads, and the water force by gravity would go on to become fundamental findings. Advancements would be made where electric and diesel pumps were implemented in systems, to achieve desired goal of water dispersion where gravity wasn't on side, or the area needed greater density of fluid dispersion.

The type of sprinkler system used in a building is determined by several factors; determining factors are the environment – inside a building or exposed to the elements, ambient temperature inside, the purpose of the building, along with the risk associated with the purpose as set out by the rules by the decided governing body – see more in subsection 'II.IV - Standards and Rules'.

II.II - Types of Systems

Wet Systems

Wet automatic sprinkler systems are the most common type of sprinkler systems in the UK, (Association, 2008), typically found in residential settings, storage facilities and healthcare settings. Wet Systems are unique in the way that they act, the only of the four main sprinkler system types to be charged with water at all time, the system has no delay in water dispersion once activated; due to this, these types of systems are primarily found where a high rate of life safety is considered, such as homes, offices, distribution and storage warehouses, manufacturing factories and even offshore oil rigs.

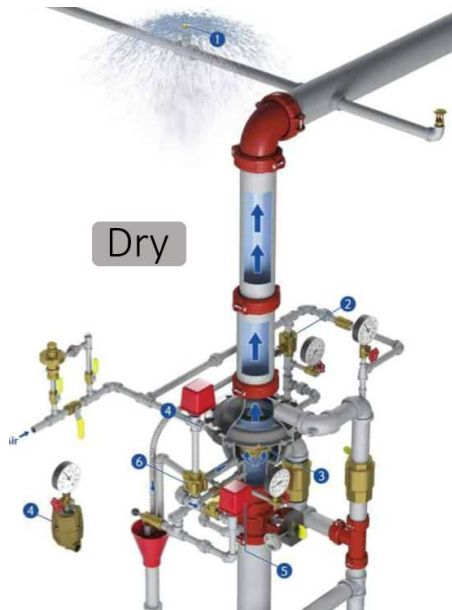


(Viking, 2019)

When the system is activated, the water held in the system will initially discharge, and once the drop in pressure is detected by the control valve, it opens, allowing water to be pumped through the source as a rate of 800-3000 Lt/min at up to 11 bar of pressure. This makes wet systems more desirable where the client requires the immediate protection and suppression.

'C' Gauge - Node	=	87
Flow	=	1429.446 Lt/min
Pressure	=	4.717 bar

Figure 5 - Calculations extracted from a recent confidential job.



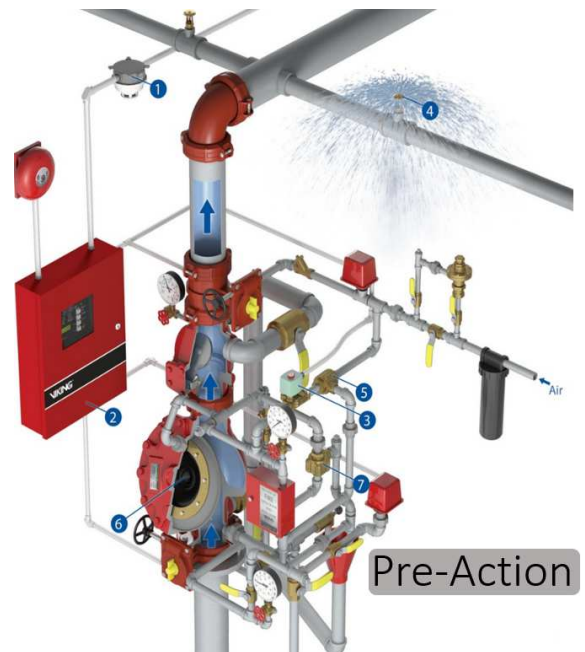
Dry Systems

Similar concept to wet, except the system is charged with pressurised air instead of water, above the control valve. This type of system is commonly used in areas where the system is susceptible to freezing temperatures, typically used in refrigerated areas or external car parks. One notation to consider with dry systems is the delay in water discharge, which depending on the hazard category, can either be 30 or 60 seconds, but this is often overlooked when compared to the cost of sealing the building and heating to be able to install a wet system.

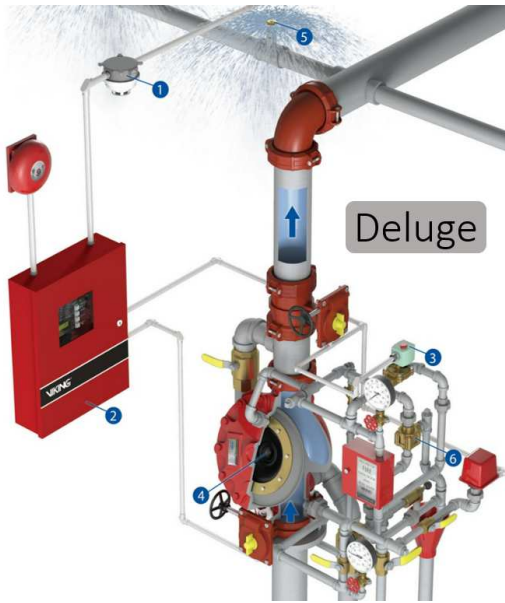
(Viking, 2019)

Pre-Action Systems

Charged with water below the control valve, and pressurised air after the control valve, essentially a dry system, which is activated upon two conditions, the bulb breaking and an electrical signal indicating fire detected (Association, 2008). Pre-action systems are ideal for use in areas where they're prone to false activation, for example likely to be knocked by a forklift inside a warehouse racking system. Another common application for pre-action systems is in water sensitive areas, usually electrical equipment storage rooms.



(Viking, 2019)



Deluge Systems

Similar to a pre action control valve, a deluge system requires an electrical signal to activate the system, where water will flood the system containing open sprinkler heads, flooding the area of deluge protection by dumping litres per minute to suppress a fire where the spread is severely costly or has a great risk of life. Deluge systems are commonly installed in paper production factories, particularly the production and storage areas.

(Viking, 2019)

II.III - Sprinkler System Effectiveness

A study conducted by Optimal Economics, in partnership with National Fire Sprinkler Network (NFSN) and National Fire Chiefs Council (NFCC), determined the effectiveness and Sprinkler Systems in the UK to be rated at 99% effectiveness and an operational reliability of 94%. (Economics, 2017)

There are a number of contributing factors to consider for the performance review of a AFSS. The purpose of a sprinkler system is to surpass the fire and prevent it spreading, which initially may make it seem difficult to review. The reliability of a system, ensuring it operates when required to do so and the efficacy, the effect of the system operating correctly affect these.

Measuring the effectiveness of a sprinkler system can be determined by:

- Containment of fire location
- Number of sprinklers activated (if systems wet/dry/pre action)
- Damage to property
- Damage to building
- Fatalities recorded
- Fire fighting service intervention.

Another consideration as to whether the sprinkler system was effective, was if the system designed for the intended building occupancy, was still applicable at the point of the fire. Building purposes change and guidance surrounding storage, in particular, is often ignored with no consideration to the impact on the function of the AFSS. The rules are constantly under review and everchanging, but the application of new rules doesn't apply to existing buildings unless rework is required. A particularly good example of the rules not being adapted but should have been is high rise building blocks used for habitation regulations, Grenfell tower for example. The incident of 2017, where the point of full extinguishment of the tower took over two hours from the full engulfment as seen below. Many conspire the smaller scale damage had a sprinkler system been in place to limit the spread of the fire, suppressing it.



More recent regulations implemented following the Grenfell Tower incident, where 72 victims died in the fire, highlighted the requirement for sprinkler systems to be present and active in more residential settings – so AFSS are becoming more frequently installed in residential settings as well as the more common commercial. We’ve seen a 68% increase in estimating jobs for residential settings in the last four years.

The rules now stipulate that residential blocks of flats above 11m in height should be fitted with Automatic Fire Sprinkler Systems (AFSS) (Government, 2019), which is less than half of the previous height requirements of 30m. This is applicable in blocks of flats, boarding houses, residential care premises, HMOs as well as individual dwellings.

The regular maintenance of AFSS is essential to the contribution of the reliability. This has been highlighted consistently in each set of rules followed internationally, specifically LPC BSEN 20.2. Inspection and Checking. Major sprinkler system components have a lifespan of 15 years, though the lifespan is based on routine testing and maintenance. Sprinkler heads have a guarantee of 25 years, with affected heads during activation evidently requiring replacement, provided the defined maintenance routine is followed.

II.IV - Standards & Rules

When designing and installing a sprinkler system, the client will involve their consultant or insurer to ensure the sprinkler system is fit for intended purpose and compliant with their requirements.

The client will liaise with the insurer beforehand to identify which set of rules the insurer requires and whether the client wants to improve on those, the final design specification will often include a cross over of standard rules, picking worst case from each to ensure maximum protection available.

Once the system is designed and installed in compliance with the chosen rules, a certificate is issued validating the protection and system – this is a requirement of the insurer. The rules are ever-changing based on new, more efficient methods and equipment.

There are three main standards used in the UK – LPC BSEN, NFPA and FM.

LPCB

Loss prevention Certification Board, LPCB is a globally recognised certifying and approval board (BRE, 2024) which provides UK companies with the appropriate certification and testing services for use in line with their rules. The certification proves that the component or set up conforms to LPC standards and is sufficient in terms of regulation.

LPC BSEN

The BS refers to British Standards European standard is the most significant standard (FPA, 2024), and the most used rule set for the projects currently undergoing by JCI and other Fire Suppression companies here in the UK. These rules refer to the European and British standards and rules for sprinkler design and operation. Initially released in 2003, the FPA and LPC continually update the rules with the latest information added as Technical Bulletins (TBs) to supersede the information in the main body of the rules. The last significant re-write of the rules where the TBs are incorporated into the body was in 2015, with another re-write due in 2025.

FM

Factory Mutual are typically the approval standards, produced by the FM Group – a sizable organisation associated with insurance (Global, 2024). Typically used by American companies who branch into the UK and want the sprinkler rules to replicate those of their existing facilities in the US.

NFPA

National fire protection association is another north American based organisation which have their own rules regarding design and function of a sprinkler system. Based in the US, the rules are globally recognised, like the FM rules.

Client specification

Where a client has the requirement for extra protection beyond any rules' minimum requirements, they will review with their own consultants and determine which density and coverage they think is the most appropriate without it being too much of a financial overspend. This is particularly the case often seen where the products are of higher value to the client than the initial overspend of the sprinkler systems' overkill.

II.III - Hydraulic Analysis

II.III.I - The Minimum Requirements

To complete the design process, the rules and client specification will require us to prove that our system is competent hydraulically, in terms of achieving the required design basis detailed in the specification. The specified design basis will include duration minimums being achieved, ensuring the pressure and velocity maximums aren't exceeded but also that the pumps and tanks are fit for purpose of contributing to the successful achievement of all the requirements.

To determine the efficiency of a sprinkler system, there are perimeters outlined within each set of rules, specifying their requirements researched to be an optimally and sufficiently performing sprinkler system.

II.III.II - Factors Affecting Fluid Flow

Firstly, to consider is the fluid delivery, ensuing the pipes are sized accordingly to the appropriate fluid deliverance, outlined in the rules based off what the sprinkler system is protecting. Ensuring we achieve the sometimes-expected 24mm/min delivery across 12 heads for 90 minutes, 300m away from the control valve can be challenging. Applying the balancing act of ensuring the flow and pressure of the fluid is sufficient for required fluid delivery, whilst not exceeding the defined maximum velocities in the rules, is critical.

The velocity of a fluid in a pipe is dependent on the fluids flow rate and the pipes area, this puts great importance on ensuring the water supplies, tank, and pump, are the most optimal for delivery, ensuring the sufficient delivery, volume and time, without exceeding the velocities outlined in the rules, posing a risk to the function of the system.

Changes in the flow rate occur based on several significant contributing factor variables, such as pressure, density, viscosity, and changes in shape/diameter of a system. The variables that are constant, or safely considered negligible in our cases are the viscosity and the density of the water. The impact of viscosity on fluid within a pipe is great on the fluid deliverance, viscosity of a non-Newtonian fluid is:

$$\tau = \mu \frac{dy}{dt}$$

Where,

μ = viscosity

τ = Shear stress

$\frac{dy}{dt}$ = Rate of shear deformation

Equation 1 - Shear Stress of a non-Newtonian fluid

(London, 2024)

Shapes and pipe sizes are constantly changing in a sprinkler systems' complicated network of feed pipes. Allowing for changes of direction for reducing architectural penetrations to suit the best layout, to tapering the mains based on the values outlined in the specified rules, the pressure in the system rides on ensuring the minimum tolerance for changes of direction are not exceeded.

II.III.III - Friction Loss Calculations

A significantly contributing factor to fluid deliverance and optimal fluid delivery performance, is the friction, essentially resistance produced in the fluid. Resistance is created from the eddy currents produced within the fluid from the roughness of the internal walls. In turbulent flow, when eddy current occurs, the fluid produces swirls and reverse current, creating resistance in the fluid. Eddy current is stronger in smaller diameter pipes, as indicated in the friction loss figures extracted from the LPC BSEN rules below.

Fittings and valves	Equivalent length of steel straight pipe for a C value of 120 ^a (m)										
	Nominal diameter (mm)										
	20	25	32	40	50	65	80	100	150	200	250
90° screwed elbow (standard)	0,76	0,77	1,0	1,2	1,5	1,9	2,4	3,0	4,3	5,7	7,4
90° welded elbow (r/d = 1,5)	0,30	0,36	0,49	0,56	0,69	0,88	1,1	1,4	2,0	2,6	3,4
45° screwed elbow (standard)	0,34	0,40	0,55	0,66	0,76	1,0	1,3	1,6	2,3	3,1	3,9
Standard screwed tee or cross (flow through branch)	1,3	1,5	2,1	2,4	2,9	3,8	4,8	6,1	8,6	11,0	14,0

Figure 6 - Table 23 from LPC BSEN 12845

(Institution, 2015)

Here the data from the credible table above illustrates the obvious decrease in equivalent lengths for larger diameters, proving the eddy current theory aforementioned.

As per the LPC BSEN rules, the system must be calculated to verify the sufficient performance, in terms of water discharge, and being within the allowable water pressure loss tolerance. This was previously calculated by hand, with pipe sizes predetermined outlined in a number of the tables within the LPC rule book, ensuring the data extracted are from the corresponding tables.

Table 30 — Range pipe diameters in OH installations

Range pipes	Layout	Diameter mm	Maximum number of sprinklers fed	
Ranges at remote end of all distribution pipes - last 2 ranges last 3 ranges last range	2-end-side layouts	25	1	
		32	2	
	3-end-side layouts	25	2	
		32	3	
	All other layouts	25	2	
		32	3	
		40	4	
		50	9	
	All other range pipes	All	25	3
			32	4
40			6	
50			9	

Figure 7 - LPC Rule Table 30

Table 32 — Range pipe diameters for HH installations with pressure and flow characteristics as given in Table 7 (1 or 2)

Range pipe	Layout	Diameter mm.	Maximum number of sprinklers fed by pipe
Ranges at remote end of all distribution pipes:	2-end-side layouts, last two ranges	25	1
		32	2
	3-end-side layouts, last three ranges	25	2
		32	3
	All other layouts, last range only	25	2
		32	3
		40	4
	Any	25	3
		32	4
All other ranges	Any	25	3
		32	4

Figure 8- LPC Rule table 32

Here it illustrates how the system type, Ordinary Hazard (OH) (figure 30) and High Hazard (HH) (figure 32) impacts the quantity of heads per range, and range size, for example for the last range, of all other layouts for OH specify that 9 heads can be fed off a 50mm range pipe, but the maximum

allowed for a HH is 4 heads on a 40mm range. These tables have been calculated using the Hazen Williams Formula.

This method is referred to as the 'pre-calculated' method, which was typically applied before the implementation and use of hydraulic software packages. As the calculations were all conducted manually, the Hazen Williams was an ideal application to calculate the rest of the piping network diameters, thanks to the substitute of the precalculated C factors, in figure 9 of table 24 from the LPB BSEN Rule book.

Table 24 — Accuracy of hydraulic calculations

Quantity	Unit	Accurate to
Length	m	0,01
Height	m	0,01
Equivalent length	m	0,01
Flow	l/min	1,0
Pressure loss	mbar/m	1,0
Pressure	mbar	1,0
Velocity	m/s	0,1
Area	m ²	0,01
Density of water application	mm/min	0,1

Figure 9 - LPC Table 24

The 'pre-calc' method, for short, requires the use of specified equipment, such as pumps and tanks, which tend to be significantly larger than the ones allowed to use through hydraulic analysis.

Understandably, the move towards the hydraulic package implementation was encouraged, as the more financially optimal process.

II.III.IV - The Hazen Williams Formula

To determine the friction loss acting on the fluid in a pipe for AFSS, there are two equations, the first being the UK predominantly used, Hazen Williams Formula. Popular due to it's ease of calculating, the Hazen Williams calculation was used for many years and is a nationally credited calculation.

The Hazen Williams equation is as follows:

$$p = \frac{6,05 \times 10^5}{C^{1,85} \times d^{4,87}} \times L \times Q^{1,85}$$

where:

- p is the pressure loss in the pipe, in bar;
- Q is the flow through the pipe, in litres per minute;
- d is the mean internal diameter of the pipe, in millimetres;
- C is a constant for the type and condition of the pipe
- L is the equivalent length of pipe and fittings, in metres.

Equation 2 – Hazen Williams Friction loss formula

(Institution, 2015)

Once deemed a credible resource, the varying and unregulated C factor of many surfaces left room for inaccuracies when using the Hazen Williams formula. The Hazen Williams calculation has, in most applications, been superseded by the other option of equation for friction loss, the Darcy-Weisbach equation. The Hazen Williams equation is largely only used for estimation of pressure drop, and frictional head loss, where water is the fluid, best applied for it's simplicity and consistency with existing data.

II.III.V - The Darcy Weisbach Formula

The Darcy-Weisbach formula fundamental in hydraulic engineering, as follows:

$$h_f = f (L/D) \times (v^2/2g)$$

where:

- h_f = head loss (m)
- f = friction factor
- L = length of pipe work (m)
- d = inner diameter of pipe work (m)
- v = velocity of fluid (m/s)
- g = acceleration due to gravity (m/s²).

Equation 3 – Darcy Weisbach friction loss formula

(PipeFlow, 2024)

Now, easily calculated through computers, which weren't previously easily accessible, making the Hazen Williams formula so popular, the Darcy-Weisbach equation holds less limitations, and provides more accurate frictional losses for different pipe roughness's. Advantageous for it's accuracy for larger diameter pipes and for higher velocity values, because of the complexity of the equation, eliminating the value of friction coefficient. The C factor values, which are taken when the velocity is 0.9m/s, means that when the velocity isn't exactly that, the C factor value is inaccurate. Typically, velocities within a sprinkler system range between 3.05 and 6.1m/s. The Hazen Williams equation also is only accurate when the fluid, is 15.6°C and subsequently the viscosity has no consideration of variance, despite learning that the viscosity can significantly impact a fluids resistance and results in a lower velocity.

Through the implementation of the Darcy-Weisbach equation, the systems pipe diameters, the pump requirements, and the energy losses can all be calculated, with accuracy, easily.

II.IV - Methodology

II.IV.I - DEMAIC & the 5S's

Reviewing the entire project process, from procurement to client handover, is essential for identifying areas where improvements can be made. By examining each stage of the process, we can identify inefficiencies and opportunities for optimisation. Lean Six Sigma tools such as DMAIC (define, measure, analyse, improve, control) and the 5S methodology (sort, set, shine, standardise, sustain) provide structured approaches to understand and enhance efficiency.

DMAIC guides us through defining project goals, measuring current performance, analysing data to identify root causes of problems, implementing improvements, and controlling for sustained results. Meanwhile, the 5S methodology, named “one of the best approaches” to implement for increased job performance (Badzran & Bazla, 2017), helps organize the workspace and standardize processes to reduce waste and increase productivity. Using both the DMAIC and 5S methodology, this will provide both quantitative data, of factual figures and procedures as well as qualitative data to explore a greater understanding and justifications.

While these tools are commonly applied in settings like workspaces or production stations, they can be adapted to suit the unique requirements of project management. Transparency from all departments is crucial to accurately pinpoint areas for improvement. The current process of designing a system, from start to finish, may not be optimised, leaving room for improvements, especially regarding time factors that directly impact costs.

II.IV.II - Interviews with Fire Suppression Design Team

Transparency from all departments is crucial for accurately identifying areas for improvement within the organization. When each department openly shares information and insights, it enables a comprehensive understanding of the entire system and its processes. This transparency enables collaboration and allows for a more thorough examination of potential optimisation opportunities.

Conducting interviews with a representative from each process involved in system design is an effective way to identify these optimisation opportunities. These interviews allow for firsthand insights into how each department operates within the current process. Process representatives can provide valuable feedback on not only the areas of improvement, but areas where measures in place work effectively and contribute to project efficiency.

During these interviews, it's essential to ask targeted questions that delve into the intricacies of the process. These questions should aim to uncover specific areas where improvements can be made,

such as workflow inefficiencies, communication breakdowns, or opportunities for automation and standardisation.

By gathering input from multiple perspectives, a more accurate assessment of the current state of the process can be made. Each individual brings unique insights and experiences, which contribute to the overall understanding of the process. This comprehensive approach ensures that all aspects of the process are thoroughly examined and that no critical issues or improvement opportunities are overlooked.

The interviews will be semi structured, with the department related questions being the focus, whilst allowing for questions tailored to the interviewee's responses. Ensuring the interviews remain effective, the techniques, in addition to the semi-structured format, and aforementioned active listening, we will encourage participation, responses remaining anonymous, and we will seek clarify where required, before summarising key points to close.

Refer to Appendix A & B for questions used through the interviews.

II.IV. III - Process Shadowing

In addition to the two methodologies of data collection discussed, process shadowing will play a crucial role in our analysis. This hands-on approach allows for a more in-depth understanding of the process by observing it in real-time.

Process shadowing provides valuable data that can be compared with past projects, enabling us to identify patterns, trends, and areas for improvement. By fully engaging in the workflow, we can uncover inefficiencies, constraints, and opportunities for optimisation that may not be apparent through other methods.

Furthermore, process shadowing helps managers gain insights into what employees require from process optimisation. By capturing their tasks and challenges firsthand, managers can better understand the practical implications of process changes and tailor solutions to meet employee needs.

The outcome of process shadowing serves two main purposes. Firstly, it enhances our understanding of the process, allowing us to make more informed decisions about optimisation strategies. Secondly, it provides employees with an opportunity to showcase their ability to identify and implement cost and time-efficient solutions. If there are any deviations from the optimised solution,

this also allows for an opportunity where employees can justify their approach, proving continuous improvement and development.

II.IV.IV - Hydraulic Software Analysis

Understanding the remaining significant part of the process is crucial. Pre-research discussions have indicated the need for optimisation in the hydraulic package used. The hydraulic package is integral to the functioning of an automatic sprinkler system; without it, the options for jobs are significantly limited. Therefore, gaining a thorough understanding of this aspect of the process is essential for ensuring the success and efficiency of the overall project.

To gain the understanding required to optimise the process revolving around the hydraulic package, an in-house hydraulics course will be undertaken, by our software developer. This hydraulic analysis, along with the other methodologies will give a full and comprehensive understanding of the use of the software for design, hydraulic analysis, verification, and validation.

V - Data Collection

With the exception of the hydraulic package analysis, for ease of coherence, data collection will be presented by the stage in the process of fire sprinkler system design and installation, rather than by the research method carried out. Methodology will be noted and referenced.

V.I - Hydraulic Package Analysis

Software developer of FireCAD, the JCI hydraulic package, provided a session of the software fundamentals, prior to the hydraulic software course, to enhance understanding.

Currently being used as a sprinkler system modelling and analysis package within our company is FireCAD. The programme was developed by a JCI employee and the rights to the package are held in house. FireCAD, a sub-product of AutoCAD, a 3D modelling software, enables the system to include the modelling of any differences in height, which significantly impacts the calculations.

Produced in the late 90s, FireCAD is employed to produce and validate sprinkler system designs and their delivery efficiency. Whilst not a recent invention, the software is regularly maintained and updated.

Through the use of the system, designers and projects can produce sprinkler systems using the fully hydraulically calculated method (FHC). This method utilises hydraulic data analysis to size aspects of the projects based on demand within the system, rather than relying on worst-case scenarios from specified rules. Ultimately, this approach saves materials, time, and money by validating that the system can operate with smaller diameters, requiring smaller tanks and pumps.

Upon user perimeter definition, illustration of the system, and running the system, FireCAD provides detailed analysis of each pipe and its quantitative data. The constitutive equation used for this calculation is the Hazen Williams equation.

The Hazen-Williams equation is used to calculate friction loss in a pipe or tube. There are such limitations to using this formula, as aforementioned, which include the fluid limitation of water only, the friction coefficient calculated when the fluid velocity is less than 1m/s, when velocities in AFSS aim to be 3-6.1m/s, but can reach up to 9m/s, and the water temperature at room temperature, which causes inaccuracies. Further details are provided in the subsection on 'II.II.III - Friction Loss Calculation'.

Attending FireCAD Beginner & Advanced courses in October 2023 and early November 2023, the knowledge of the abilities of the software, along with the, seeming endless possibilities for variables

to determine the hydraulic calculations. The findings of user input parameters can be compared to those found through the process shadowing of both, procurement, and design teams.

It's interesting to note the automatically selected user parameters for the calculations. By default, the formula used for calculating friction loss is the Hazen Williams equation. While this equation is generally acceptable for calculating friction loss, it may not always be the most appropriate or best choice. The FireCAD developer advised that as per (Association, 2008), clause 13.2, the rules stipulate, the Hazen Williams calculation is to be used, see figure 10.

13.2 Calculation of pressure losses in pipework

13.2.1 Pipe friction loss

Calculations of pipe friction loss shall be not less than those derived from the Hazen-Williams formula:

$$p = \frac{6,05 \times 10^5}{C^{1,85} \times d^{4,87}} \times L \times Q^{1,85}$$

where:

- p is the pressure loss in the pipe, in bar;
- Q is the flow through the pipe, in litres per minute;
- d is the mean internal diameter of the pipe, in millimetres;
- C is a constant for the type and condition of the pipe (see Table 22);
- L is the equivalent length of pipe and fittings, in metres.

Figure 10 - LPC requiring friction loss to be calculated by Hazen Williams formula

(Association, 2008)

Along with this default parameter, the preselected material selection for the pipe is cast iron, with a c factor, as outlined in (Association, 2008) to be 100. Through simple analysis of the Hazen Williams equation, the correlation between the c factor and friction is evident: the higher the c factor, the smaller the friction, and therefore less energy loss for the water flowing in the pipe.

Table 22 — C values for various types of pipe

Type of pipe	Value of C
cast iron	100
ductile iron	110
mild steel	120
galvanized steel	120
spun cement	130
cement lined cast iron	130
stainless steel	140
copper	140
reinforced glass fibre	140
NOTE The list is not exhaustive.	

Figure 11 - C factors to be used by LPC for friction loss

(Association, 2008)

FireCAD software engineer justified that whilst the cast iron is commonly used for previous jobs, for underground pipework, all FireCAD users are advised to change their pipe selection and ensure it's correct for calculation and verification purposes.

V.II - Procurement, Design, and Installation: Complete Process Review and Analysis.

Reviewing the current entire project process, procurement to client handover, allows for in depth analysis to identify areas in which improvements can be made.

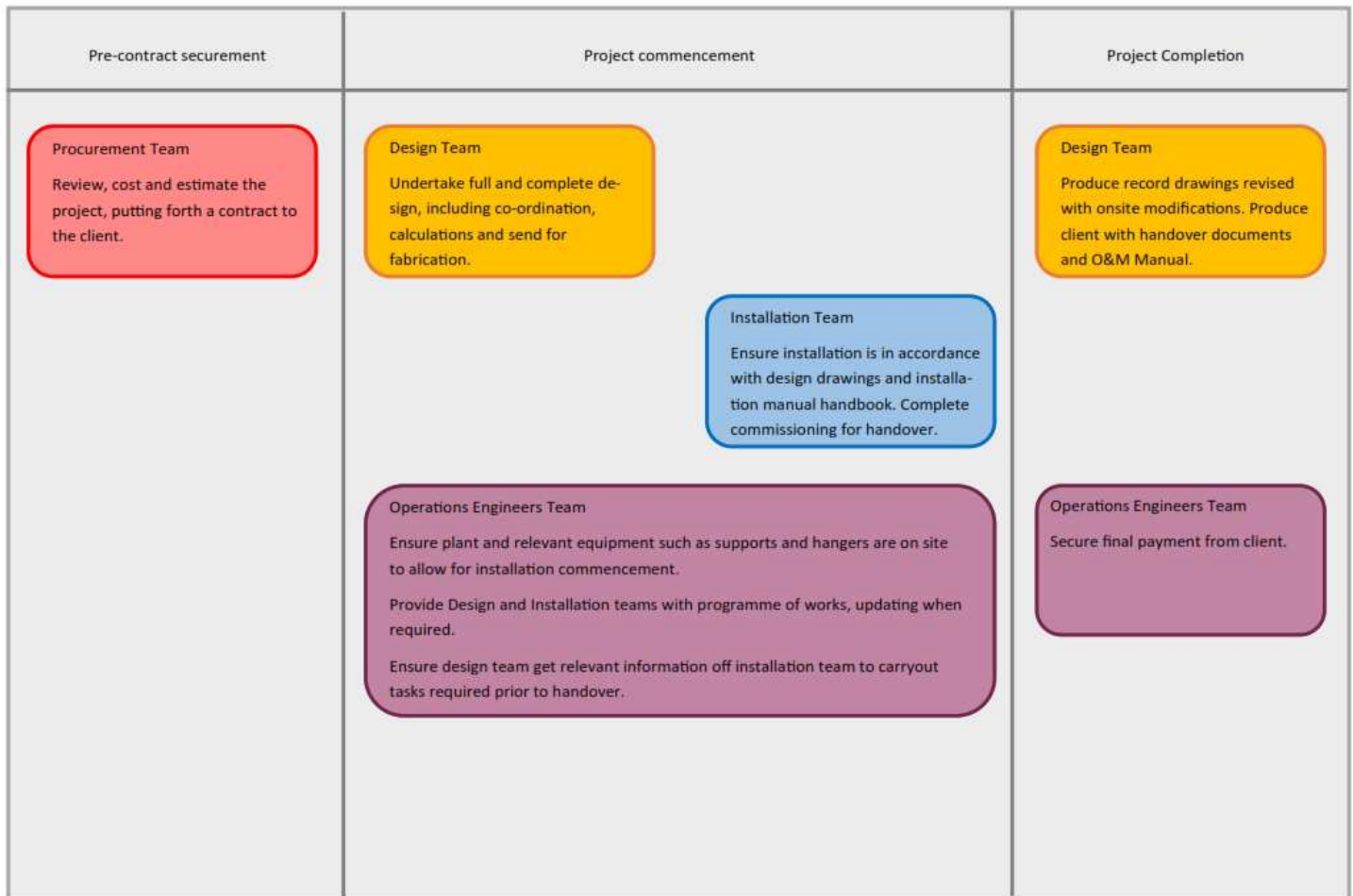


Figure 12 - Process chart of sprinkler system planning and installation.

The chart here illustrates the departments involvement and associated tasks. This overall process diagram will aid in the review of the process review of each department, asking each department to ensure the tasks listed above are completed, and if not, provide viable justification, ie method improvements. The process chart shows that theoretically there should be no bottlenecks, no duplication of efforts and all work carried out within compliance. Realistically this isn't the case, and through the methods outlined previously, we will identify these problematic areas and optimisation opportunities.

To accurately identify areas of possible improvement, the transparency from all departments is critical. The current process of designing a system, start to finish isn't currently the best it can be, leaving room for optimising the process considering time factors which are ultimately cost factors.

Conducting interviews with a dedicated colleague from each process will aid in identifying these optimisation opportunities.

Prior to commencing the process shadowing, it's important to identify if there is a set process implemented, and if it is followed will be determined by the shadowing. Departmental leads can confirm if there are process documents in place to provide structure to the different tasks at each stage.

V.II.I - Procurement

Interviews with the procurement team started with the departmental leads, identified their suggested improvements, and provided a diagram the procurement are directed to follow, figure 13.

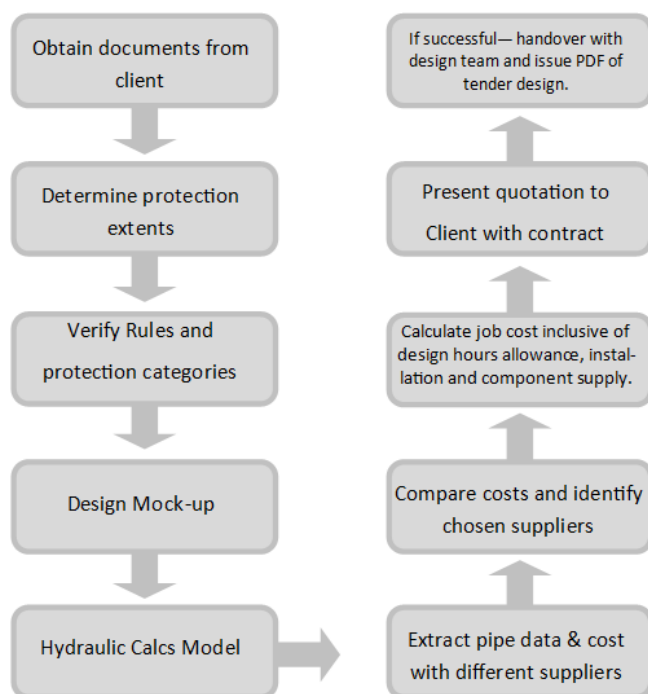


Figure 13- process chart for the procurement department.

Interviews with the procurement team entailed a run through of the project procurement process, describing the fundamentals of each step. This includes, understanding the full scope of work, identifying categories and subsequently the requirements of protection, design for approximate fabrication and installation costs, hydraulic calculations for verification of water supplies and providing cost analysis for the next stages, the design, and installation.

Interviews conducted with a procurement team representative, through the application of the semi-structured interview concluded that there is generally an overspend on pipe costing, both fabrication and install, compared to previous contracts. The interviewee speculated that when

comparing hydraulic output of the pipe system to another software, the FireCAD software will output that larger diameter pipes are required. Identifying the potential root cause, as the use of the FireCAD software, indicating further review with users of the software, and the software engineer.

The procurement representative also indicated that another time-consuming stage of the process was when the client changes the scope of work, or the category, impacting the protection type and density, when the procurement team are passed design mock up. This is typically a cost that's absorbed and an unforeseen circumstance which is dismissed in the case of job loss, or recovered if the job is secured.

Process shadowing is pivotal in this review and analysis, giving a clear indication of the estimators' knowledge of best practices to adopt and their consideration all options, this information is only something that can be reviewed by shadowing on an individual case basis.

Shadowing of the procurement provided this vital information, in aid of the research stage. Whilst the interview indicated that the best practise is always followed, the shadowing indicates that further training is required, based around most optimal decisions, cost, and time focused. Examples of this poor-practice design included uncommon designs which utilise more product, and result in more expensive outsourcing, such as fabrication and installation. During the process justification, the reasoning was simply ignorance, the design team for the procurement are inexperienced in choosing best and most appropriate practices.

Reviewing previous jobs as a baseline average comparator, the gap between utilised hours for the procurement team to conduct their process, has grown significantly over the years. Procurement justification indicates back to the previously highlighted issue relating to changes to the scope of work. It is highlighted that the design will often be based on the main contractors' work in progress (WIP) drawings, and so changes often occur at design stage. This is worth noting as this isn't part of the original costed plan and needs verification it's within the tolerances of change of design, again recovering costs at a later date.

It's of particular interest that FireCAD re-training may be required for some designers within the procurement process. Shadowing concluded that a small number of the subjects being shadowed, provided sufficient knowledge for the options and settings available and used in FireCAD. Only a small number altered the rule selection, the pipe material selection and reverted to the Darcy-Weinbach formula for calculating friction loss.

Following the securement of the contract, the next stage of the process of the sprinkler design process is onto the design team.

V.II.II - Design

The design team were reviewed using the same approach, shadowing of the design process, with appropriate describing and justification of process to ensure financially optimal design is being adopted, if not, considered at least.

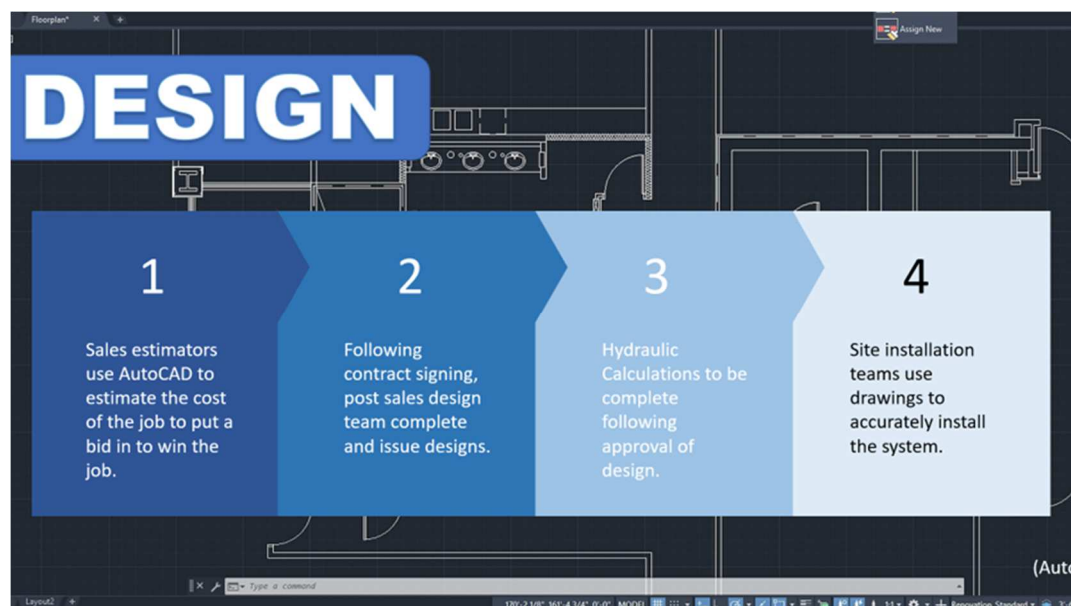


Figure 14 - process chart for the design department.

After conducting research through DMAIC (Define, Measure, Analyse, Improve, Control) and 5S methodology, as well as a thorough process review, it has become evident that there are several factors contributing to excessive cost waste in the design and installation of fire sprinkler systems.

One key area for optimisation lies in the hydraulic calculation process, where more efficient adaptations within the software can lead to significant cost savings.

Through the analysis phase of the DMAIC methodology, it was found that the current hydraulic calculation process is not optimised, leading to unnecessary costs. Aforementioned, the software using Hazen Williams number, as opposed to the Darcy Weisbach, means larger diameter pipes are required, by implementing the Darcy Weisbach formula, smaller pipes can be used, which are not only cheaper to fabricate but also install, substantial savings can be realized without compromising system performance or safety standards.

Upon further analysis, it was determined that the installation process could also benefit from hydraulic optimisation. Currently, installation costs are high, especially for larger pipes, which require more labour and materials. However, if the design can be optimised to use smaller pipes

without sacrificing performance, significant cost savings can be achieved in both fabrication and installation.

Furthermore, improved coordination between the procurement and installation departments is essential for ensuring that the correct materials are delivered on time, reducing delays and additional costs associated with last-minute changes or rush orders. This aligns with the principles of Shine (Seiso) and Standardize (Seiketsu) in the 5S methodology, where processes are standardized and continuously improved for maximum efficiency.

Using the 5S methodology, it was observed that there is an opportunity to streamline the handover process between the design and procurement departments. Currently, the procurement team provides hydraulic calculations and designs in PDF format, requiring the design team to rework the drawing into a cad format. This results in double working and unnecessary time expenditure.

By transitioning to providing procurement costing drawings and hydraulics in DWG files, a more efficient format for procurement, the process would be streamlined, saving time, and subsequently reducing costs. This simple adjustment aligns with the principles of Sort (Seiri) and Set in Order (Seiton) within the 5S methodology, where unnecessary steps are eliminated, and workflows are organised for maximum efficiency.

Shadow processing from the representative of the design team also highlighted a few noteworthy practices, it was raised that often, when a 'rush job' is on, there's typically pipes already been fabricated and onsite, before the design tasks land with a designer. This is absolutely discouraged and is not in line with any of the rules. Difficult tasks associated with trying to make the pre-ordered fabricated pipe work within the system, in terms of design and hydraulics are very time consuming. Justification of this behaviour is that the pressure from the project operations means that if a job isn't done fast enough, they take over.

This practice poses significant challenges, particularly in terms of regulatory compliance, and may result in repercussions if the contract is selected for the bi-annual audit and such malpractice is identified. It is imperative that this issue is promptly addressed and rectified to prevent further escalation.

V.II.III - Operations and Installation

Operations teams are a pivotal role in the installation of the sprinkler system, contracting an subcontractor team to conduct the installation, ensuring the drawings are sent to fabricator, to accepting the scheduled deliveries of components. other tasks of a project operations team involve, the scheduling of essential equipment, like MEWPS, critical for the installation of the systems.

Timing and efficiency are detrimental to reduce delay costs associated with behind schedule of the installation, or even delay of return costs from plant hire companies.

The pre-contractual works assessment is the responsibility of the project manager (operations), is conducted before the programme of works is scheduled, ensuring the sites conditions are adequate for a start date without posing delays. The site check involves the adequacy of utilities at the installation sites, these frequently poses a challenge often drop out without prior communication, causing significant delays.

Overseeing the installation teams work, identifying any areas if inaccuracies or noncompliance and relaying information to the design team where the layout of the sprinkler system had to be modified on site, to ensure they update the drawings for a true reflection.

Verifying the required trip times, and the pumps flows to relay to design teams to validate the hydraulic calculations further is another essential role by the operations and installations teams.

VI.I - Interview Review

Interview responses are available for full review in appendix C & D.

While interviewing a larger group would have been ideal to gain a more comprehensive understanding of the issues faced, we were limited to interviewing one representative from each department. To compensate for this, the representatives engaged extensively with their respective teams to gather a wide range of insights. This approach helped capture a detailed and accurate picture of the difficulties encountered in the design and installation process.

VI.I.I - Procurement

The interview responses highlighted challenges related to stock shortages, delays, and the difficulties in finding reliable suppliers. This draws attention to supply issues, indicating that while there is a good understanding of using optimal components and methods, external factors often prevent this from being implemented. These findings reinforce those from the process shadowing and review.

VI.I.II - Design

The design team representative highlighted time constraints and the challenges associated with unplanned revisions and rework of the design and hydraulics from the beginning. Although there is a process plan in place, different contract types require variations based on other job requirements. Streamlining the process through improved communication from procurement was identified as a potential optimisation technique, along with clarity regarding design requirements.

A suggestion was made for a more detailed tender outlining exact system and job requirements. Additionally, upgrading hydraulic software was proposed to help eliminate discrepancies resulting from input data inaccuracies.

VI.I.III - Installation and Operations

In addition to procurement facing challenges with stockage, the installation and operations teams have also identified sourcing issues. Late deliveries, despite regular tracking, have a cascading effect on the project installation timeline.

The reviews also identified the dropout of utilities and their imposed delays as problematic, as this is becoming a more frequent instance.

Furthermore, subcontracting work to external installation teams reveals the frequent use of oversized pipes, impacting both cost and installation time.

It is crucial for the planned scope of works to consider any factors that may affect installation, such as access restrictions or power outages. Operations must identify these instances so that time can be allocated for other areas of installation.

VII - Identifying and Implementing Optimising Techniques

VII.I - Identifying Solutions

The data collected from the process revealed a common factor underlying all optimisation opportunities: the need to rework the hydraulic analysis software. While the current software is valuable, there is an urgent need to implement suggestions from the data collection to enhance its efficiency. In short, an improved calculation process would address several of the cost-draining factors.

Identifying Solutions

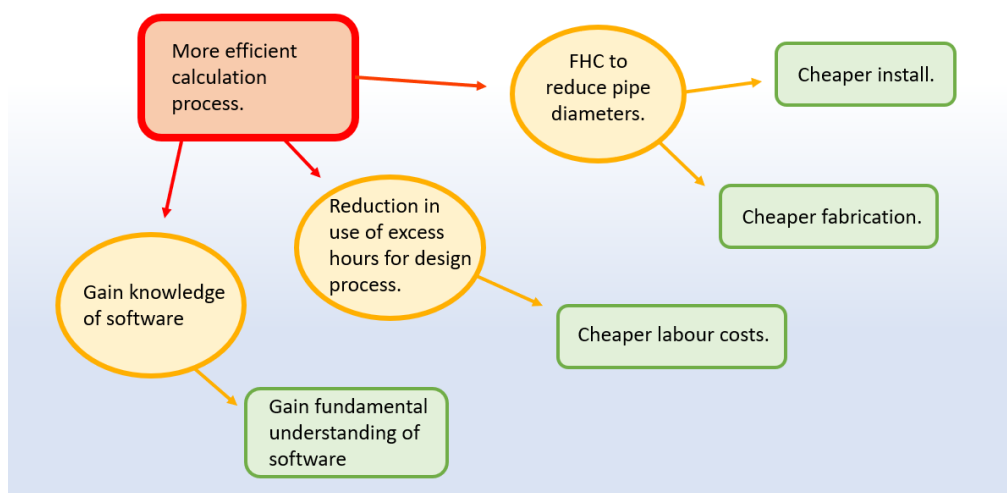


Figure 15 - possible process optimisation techniques identified.

Armed with feedback and necessary approvals to conduct the research and allocate hours for reworking the project, the software development team was tasked with enhancing the software.

The rework specifications are outlined as follows:

- User to define pipe specifications before enabling the insertion of pipe.
- User to define rules and design parameters.
- User to define frictional loss formula, with default or first option to be Darcy Weisbach.

Another commonly identified issue was related to process and communication. Following discussions with department heads and later involving all relevant employees, a new process plan has been devised to address this concern. This plan aims to capture a multitude of possibilities

within the design specifications, ensuring a comprehensive approach to all aspects of the Automatic Fire Sprinkler System (AFSS) design and installation.

A key component of this new process is the development of a detailed tender document, which will serve as a foundational blueprint for the project. The new tender proposal will include the following specifications:

- Detailed design specifications encompassing all technical regulations.
- Specified design densities inline with the outlined rules, specific for each category and individual requirements.
- Task association for tasks within the whole AFSS design and installation process, to ensure clarity and prevent double work.

This tender proposal specification will improve the general project understanding of all those involved. When implementing this with the next specified change, improved communication.

Effective communication is crucial for the success of projects like these. To facilitate a smooth process, the comprehensive transfer of knowledge is essential. One highlighted issue is the double working caused by procurement only transferring PDFs. To correct this, a new protocol for transferring DWG files will be implemented. Additionally, the procurement department must ensure effective handovers by providing clear and complete information. This clarity will eliminate the back-and-forth inquiries from the design team that result from receiving incomplete information.

By addressing these communication and knowledge transfer issues, the process will be more efficient, reducing delays and improving the overall workflow for the design and installation teams.

VII.II - Implementation and Testing

VII.II.I - Hydraulic Package Revision

Following the completion of software development, a small beta testing group evaluated its efficiency before the national rollout. This phase also served to identify any bugs, glitches, or irrelevant features that could be eliminated. The test spanned over a 30-day period to assess its practical effectiveness. Testing was conducted on completed jobs to ensure fair comparisons, involving a complete resizing of pipe diameters throughout the sprinkler system. System 1, the test first retesting subject, was a previous contract of a dry soffit system installed in a carpark. Ensuring the latest supplier costs are available, using one of our frequented suppliers. Comparing the results of System 1, original and retest, it is evident that the new software led to smaller pipe diameters,

resulting in reduced costs for fabrication and installation. See figures 16,17 and 18,19 for before and after pipe totals and costing exercise. Optimisation revealed that the sprinkler system remains effective while achieving a significant cost saving of 13% on pipework alone.

212.37 of 25mm pipe
362.26 of 32mm pipe
126.66 of 40mm pipe
15.18 of 50mm pipe
84.47 of 65mm pipe
124.42 of 80mm pipe
69.82 of 100mm pipe
124.49 of 150mm pipe

Figure 16 Pipe Diameters of System 1 before new software revisions.

	Base Rate	Unit Value	Line Quantity	Line Value	Multiplier	Total
Issue date 16/03/2024	£	£	Metres, Pieces or Tonnes	£	100%	£
200MM SCH20 TUBE API 5L	£46.47	£46.47		£0.00		
150MM MEDIUM QUALITY TUBE	£23.80	£23.80	125.00	£2,975.00		
100MM MEDIUM QUALITY TUBE	£15.13	£15.13	70.00	£1,059.10		
80MM MEDIUM QUALITY TUBE	£10.69	£10.69	125.00	£1,336.25		
65MM MEDIUM QUALITY TUBE	£8.17	£8.17	85.00	£694.45		
50MM MEDIUM QUALITY TUBE	£6.05	£6.05	15.00	£90.75		
40MM MEDIUM QUALITY TUBE	£4.30	£4.30	125.00	£537.50		
32MM MEDIUM QUALITY TUBE	£3.73	£3.73	360.00	£1,342.80		
25MM MEDIUM QUALITY TUBE	£2.95	£2.95	210.00	£619.50		£8,655.35

Figure 17 before optimised software costing exercise of System 1.

345.77 of 25mm pipe
339.34 of 32mm pipe
16.17 of 40mm pipe
24.85 of 50mm pipe
151.59 of 65mm pipe
113.98 of 80mm pipe
60.73 of 100mm pipe
67.24 of 150mm pipe

Figure 18 Pipe Diameters of System 1 after new software revisions.

	Base Rate	Unit Value	Line Quantity	Line Value	Multiplier	Total
Issue date 16/03/2024	£	£	Metres, Pieces or Tonnes	£	100%	£
200MM SCH20 TUBE API 5L	£46.47	£46.47		£0.00		
150MM MEDIUM QUALITY TUBE	£23.80	£23.80	67.00	£1,594.60		
100MM MEDIUM QUALITY TUBE	£15.13	£15.13	60.00	£907.80		
80MM MEDIUM QUALITY TUBE	£10.69	£10.69	115.00	£1,229.35		
65MM MEDIUM QUALITY TUBE	£8.17	£8.17	150.00	£1,225.50		
50MM MEDIUM QUALITY TUBE	£6.05	£6.05	25.00	£151.25		
40MM MEDIUM QUALITY TUBE	£4.30	£4.30	16.00	£68.80		
32MM MEDIUM QUALITY TUBE	£3.73	£3.73	340.00	£1,268.20		
25MM MEDIUM QUALITY TUBE	£2.95	£2.95	345.00	£1,017.75		£7,463.25

Figure 19 after optimisation costing exercise of System 1.

System test subjects 2, 3, and 4 were selected from a variety of jobs to ensure fairness in testing. These included a wet system, a racking system, and another roof system. All subjects demonstrated identical results, with savings ranging between 10% and 18% on pipework alone. Undoubtedly, the smaller pipe diameters led to cheaper fabrication and installation costs, before factoring in external contributing factors such as trace heating and lagging, which are dependent on the length and diameter of the pipe.

VII.II.II - Improved Communication & Requirement Understanding

The roll out of the newly reproduced tender document, detailing specifically and accurately what is included in the procurement stage of costing, commenced in the testing period. Due to time constraints, this testing was rolled out to all contacts (9) handed over from procurement to design during February and March 2024. The rollout success can only be measured by feedback at this stage from both design and procurement. Time constraints restricted a full analysis of the projects progress with the new implemented tender document.

The feedback received from procurement and the design teams was via an online 'teams', team discussions. The feedback was generally positive, with beneficial comments on aspects captured well, regarding the new structure (Participant 1. , 2024), as seen in figure 20 , allowing an ease of finding of information. A particular standout aspect of the new tender proposal document is the documentation of client drawings used for costing and also the denoting of the design procurement engineers responsible for design and costing.

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Figure 20 - New Tender Table of Contents

Recognition is provided for referencing the selected rules, facilitating the work of the design engineering team and minimizing the need for excessive iteration.

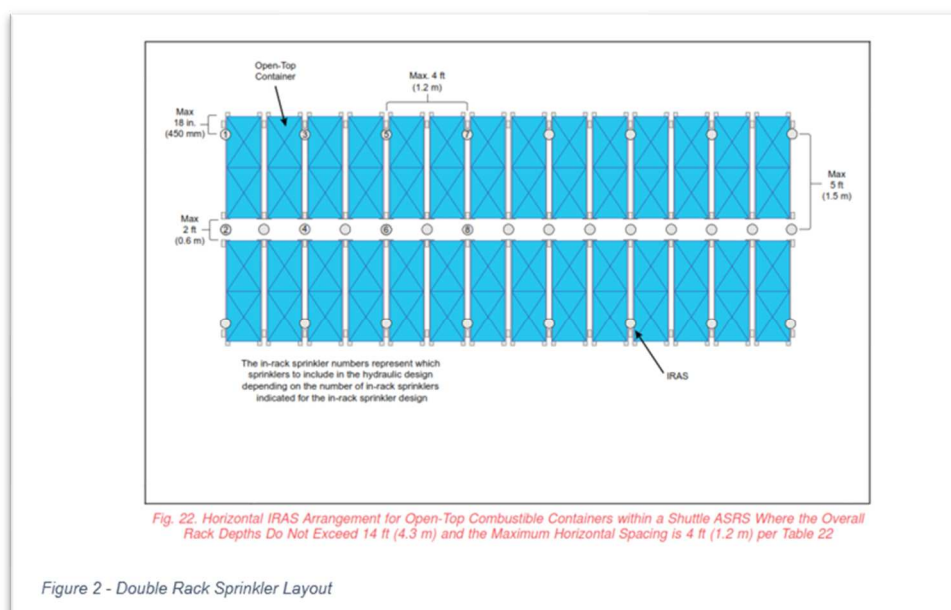


Figure 21 - New tender referencing applicable rules.

Figure 3 - Single Rack Sprinkler Layout

Figures 19, 22, or 25	Unexpanded Plastic	Any	Wet	10 (3.0)	100 (380)	11.2 (160)	6 on top IRAS level	No
				15 (4.6)	140 (530)	22.4 (320) Pendent	6 on top IRAS level	No
			Dry	10 (3.0)	100 (380)	11.2 (160) Upright	8 if one IRAS level or 14 (7 on top 2 levels)	Yes

Figure 22 - New tender referencing applicable rules.

Continuing to address overcoming issues raised between design and procurement, the process of the handover has been adapted, now to include the transfer of files in DWG format, as well as PDF. (Participant 1. , 2024) commented how this has been exceptionally helpful for the software calculation verification process.

Following concerns raised during installation, we've addressed the lack of a program plan of works by including a base plan. The operations team will finalize this upon contract signing. Additionally, we've added a clause regarding resource issues, making any cost-impacting delays chargeable to the client. This addition has been well-received as a 'valuable inclusion', (Participant 4. , 2024) noting.

3.2: Installation Strategy

This proposal and the preliminary timing plan detailed above are based upon certain site conditions being met, these include:

- // For a project of this duration and complexity TFIS would include for a visiting Site Supervisor.
- // Site Install works to be completed in one continuous visit, with clear and uninterrupted access to work areas as required, during our normal working hours, i.e. 8am to 6pm Monday – Friday (excluding Bank Holidays).
- // Our proposal has been based upon agreeing an installation sequence which will enable uninterrupted installation of protection within the racking/pick tower.
- // Key dependencies being complete and available to facilitate our works, these include:
 - //
 - Adequate Water Supply
 - Electrical Supply
 - Single Face Rack Construction to agreed schedule – 1/13 of the racking is to made available at any given time to allow for sequential working.

Figure 23 Installation Strategy from new tender proposal.

Addressing another issue faced by the design team, we have now included a section in the document referring to the release of drawing schedules and its dependence on complete client information. This addition was well-received by the design team, as incomplete client information often caused difficulties for them. Highlighting the ease of cost recovery with this information, (Participant 1. , 2024) is eager to demonstrate its impact on the process and cost savings.

To tackle communication and clarification issues between procurement and design teams, the final section of the improved tender document includes a comprehensive list of responsibilities, covering those of JCI and the client, as well as a section for items that are not applicable. This section clearly defines the responsibilities of JCI and the client, providing clarity on each task within the processes. (Participant 2. , 2024) highlighted that this section is particularly valuable for inexperienced engineers.

Acknowledging the positive comments while also considering further improvement suggestions, several areas were highlighted for enhancement. Although the new document has been created, its effectiveness will only be realized through its utilization. It is noted that the document's value is dependent on the procurement team's knowledge, with additional training emphasized as a requirement across the board (Participant 7. , 2024). Discussions within the group also touched upon the significance of staying updated with the ever-changing rules (Participant 5. , 2024).

VIII - Conclusion

VIII.I - Introduction

In conclusion, this project aimed to improve the efficiency of sprinkler system planning and installation, specifically focusing on cost-effectiveness. Given the recent identified reduction in profit margins by 8-12% from jobs, there was a significant need to identify areas for process and cost optimisation. Through the utilization of appropriate literature and analysis techniques, we aimed to identify a more streamlined process to reduce costs and enhance overall efficiency, while also implementing general process improvements using the 5S methodology.

Prior to the project, thorough research was conducted to gain a foundational understanding of sprinkler systems, software analysis, and the entire process involved in bidding, designing, and installing automatic fire sprinkler systems. Additionally, department representatives were interviewed to gather frontline opinions. This comprehensive approach allowed for a thorough review of the entire process to identify potential areas for improvement.

The findings from this project will serve as a roadmap for enhancing cost efficiency in sprinkler system projects while maintaining safety standards and maximizing profitability. By integrating insights from frontline representatives, alongside the research conducted, the project outcomes provide valuable guidance for optimising processes and achieving cost-effective solutions in fire sprinkler system projects.

VIII.II - Findings from Literature Review

In conclusion, the literature review has highlighted several crucial considerations for optimising sprinkler systems, including the preference for the Darcy-Weisbach formula over the Hazen-Williams formula for calculating friction loss in pipe systems. This choice is significant due to the Darcy-Weisbach formula's accuracy, particularly in systems with varying flow conditions and pipe characteristics.

The review also highlighted the role of advanced software analysis tools in streamlining system design and installation processes. These tools enable accurate cost estimation and optimisation, contributing to overall project efficiency, when used appropriately.

Additionally, the review emphasized the importance of staying up to date with the ever-changing rules and regulations governing sprinkler system design and installation. Changes in regulations can significantly impact the effectiveness of a sprinkler system's performance, as non-compliance may

lead to safety hazards and increased liabilities. Therefore, maintaining awareness of these changes is essential for ensuring that systems remain compliant and effective over time.

Leading onto the emphasis of the essential ongoing training and professional development for involved personnel of sprinkler system design and hydraulic analysis. Continuous application of best practice techniques, as well as adopting new regulations will result in improved project outcomes.

VIII.III - Overall Summary & Final Comments

In pursuit of enhancing the efficiency of the sprinkler system planning and installation with a particular emphasis on cost effectiveness, the project integrated fundamental knowledge gained from an extensive literature review, followed by data collection through interviews, process shadowing and analysis using DMAIC and 5S methodologies. The findings from this comprehensive study provided significantly optimising solution insights for sprinkler system design and installation process, emphasising on hydraulic analysis and communication clarity.

The literature review emphasised the degree of accuracy achieved through Darcy Weisbach formula over the Hazen Williams formula for hydraulic analysis, making it a superior alternative. This insight was further proved as the foundation of the project, armed with the possibility of providing the desired financial savings in association with the ability to use smaller pipes, saving on fabrication and installation costs. The software was updated to perform optimally and implement the Darcy Weisbach formula.

Additionally, interviews highlighted optimisation opportunities surrounding clarify and communication across departments. In particular, the transfer of files, and being clear of the specific design requirements of the system. The findings of this resulted in the tender proposal being re-worked based on issues highlighted, with the aim of maximising design efficiency and project execution.

Subsequent beta testing proved the effectiveness of the FireCAD change, achieving the intended objective of cost reduction in installation through the utilization of smaller pipe diameters, all while ensuring compliance.

During beta testing, the new tender proposal document was issued to assess team opinions and the effectiveness of the structured approach. It now addresses commonly overlooked subjects, such as utility availabilities and adherence to the program of works, to mitigate delay penalties to the contractor. The revised proposal received positive feedback for its enhanced clarity and comprehensive coverage of critical aspects, including utility availability and project timelines.

In conclusion, the findings of this report demonstrate the effectiveness of optimising sprinkler system planning and installation with a cost focused approach. The adoption of the Darcy Weisbach formula, along with ensuring communication clarity will be the most impactful change. Monitoring of these is essential for sustaining desired profit margins and operational excellence.

VIII.IV - Limitations of study

During the data collection phase, it became evident that while the DMAIC process was utilized as the overarching framework, the 5S methodology proved to be more practical and beneficial due to the extensive reviews required for each stage of the process. This led to a limitation in the comprehensive application of the DMAIC methodology. Additionally, time constraints-imposed limitations on conducting a thorough analysis of the effectiveness of the new tender documents in enhancing process efficiency. As a result, further evaluation of efficiency will be necessary upon completion of contracted projects.

VIII.V - Recommendations for further work

A thorough evaluation of the new tender proposal's effectiveness is essential and should involve comprehensive testing across various projects. This evaluation needs to consider factors like job type, designer, and system type to ensure fair and accurate assessment. Additionally, it's recommended to assess its impact on key performance indicators such as project completion time, cost efficiency, and client satisfaction.

Another suggestion involves providing ongoing professional development through enhanced training sessions for FireCAD, targeting all members of the design and procurement teams. This additional training aims to enhance time efficiency by equipping individuals with a comprehensive understanding of the capabilities of this invaluable software.

Another suggestion is to conduct bi-annual reviews to maintain long-term process efficiency, building upon the insights gained from these reports. These reviews should analyse project completion data and assess processes to ensure ongoing relevance and adherence to best practices.

Implementing these recommendations alongside evaluating the new tender proposal will further optimise the efficiency and effectiveness of the sprinkler system planning and installation process, ultimately leading to improved project outcomes and client satisfaction.

IX – Appendix

Appendix A – Questions for interviews

Procurement & Design

1. What are the main challenges you face in the current sprinkler system planning process?
2. How do you ensure clarity and ease of interpretation when navigating through the rules and regulations governing procurement processes?
3. In your strategy, what methodologies or frameworks do you employ to identify and prioritize the most cost-optimizing methods?
4. How do you perceive the effectiveness of the current hydraulic analysis methods?
5. Identify any positives of the current process.
6. Identify any bottlenecks or steps requiring improvement.

Appendix B – Questions for interviews

Installation/Operations

1. What are the main challenges you face in the current sprinkler system installation process?
2. What are the primary challenges your team encounters during the current sprinkler system installation and operations process?
3. What are the primary challenges your team encounters during the current sprinkler system installation and operations process?
4. Identify any positives of the current process.
5. Identify any bottlenecks or steps requiring improvement.
6. How is the communication between departments, and how does this affect installation?

Appendix C – Interview Answers

Procurement

1. The main challenges in the sprinkler system planning process involve frequent stock shortages, delays, and difficulties in finding dependable suppliers.
2. Clarity and ease of interpretation in navigating procurement regulations are ensured through regular training sessions, clear documentation, and access to legal expertise when needed.
3. Our strategy employs methodologies like total cost of ownership analysis and value engineering to identify and prioritize the most cost-optimizing methods in procurement decision.
4. The current hydraulic analysis methods are perceived to be moderately effective, but there is room for improvement in accuracy and efficiency to ensure optimal system performance.
5. Positives of the current process include a good understanding of using optimal components and methods, contributing to overall system effectiveness.
6. Bottlenecks requiring improvement include addressing stock shortages, streamlining supplier selection processes, and enhancing communication channels to mitigate delays and improve overall efficiency in procurement operations.

Design

1. As a design engineer, the main challenges in the sprinkler system planning process involve time constraints and the difficulties associated with unplanned revisions and rework of the design and hydraulics.
2. Clarity and ease of interpretation in navigating procurement regulations are vital for ensuring seamless integration of design requirements with procurement processes, promoting efficiency and minimizing delays.
3. In our strategy, we employ methodologies such as comprehensive system modelling and iterative design reviews to identify and prioritize the most cost-effective and technically viable solutions.
4. The effectiveness of the current hydraulic analysis methods is perceived to be moderate, but there is a need for improved accuracy and efficiency to streamline the design process and minimize revisions.
5. Positives of the current process include having a structured process plan in place, although there is recognition of the need for improvements to address variations in contract types and job requirements.
6. Bottlenecks requiring improvement include enhancing communication with procurement to streamline processes, ensuring clarity regarding design requirements, and implementing upgrades to hydraulic software to eliminate discrepancies resulting from input data inaccuracies.

Appendix D – Interview Answers

Installation/Operations

1. The main challenges we face in the current sprinkler system installation process include sourcing issues, late deliveries despite regular tracking efforts, and utility dropouts leading to project delays.
2. Our team encounters challenges such as sourcing issues, late deliveries, and utility dropouts during the sprinkler system installation and operations process.
3. Primary challenges in the sprinkler system installation and operations process revolve around sourcing issues, late deliveries, and utility dropouts, all of which impact project timelines and efficiency.
4. Despite the challenges, one positive aspect of the current process is the regular tracking of deliveries, which helps in identifying potential delays early on.
5. Bottlenecks or steps requiring improvement include addressing sourcing issues, streamlining delivery schedules, and implementing measures to mitigate the impact of utility dropouts on project timelines.
6. Communication between departments is crucial for successful installation. Lack of communication or delays in information sharing can lead to coordination issues and affect the installation process, especially when dealing with subcontracted teams and external suppliers.

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	Base Rate	Unit Value	Line Quantity	Line Value	Multiplier	Total
Issue date 16/03/2024	£	£	Metres, Pieces or Tonnes	£	100%	£
200MM SCH20 TUBE API 5L	£46.47	£46.47		£0.00		
150MM MEDIUM QUALITY TUBE	£23.80	£23.80	125.00	£2,975.00		
100MM MEDIUM QUALITY TUBE	£15.13	£15.13	70.00	£1,059.10		
80MM MEDIUM QUALITY TUBE	£10.69	£10.69	125.00	£1,336.25		
65MM MEDIUM QUALITY TUBE	£8.17	£8.17	85.00	£694.45		
50MM MEDIUM QUALITY TUBE	£6.05	£6.05	15.00	£90.75		
40MM MEDIUM QUALITY TUBE	£4.30	£4.30	125.00	£537.50		
32MM MEDIUM QUALITY TUBE	£3.73	£3.73	360.00	£1,342.80		
25MM MEDIUM QUALITY TUBE	£2.95	£2.95	210.00	£619.50		£8,655.35

.....	38
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	Base Rate	Unit Value	Line Quantity	Line Value	Multiplier	Total
Issue date 16/03/2024	£	£	Metres, Pieces or Tonnes	£	100%	£
200MM SCH20 TUBE API 5L	£46.47	£46.47		£0.00		
150MM MEDIUM QUALITY TUBE	£23.80	£23.80	67.00	£1,594.60		
100MM MEDIUM QUALITY TUBE	£15.13	£15.13	60.00	£907.80		
80MM MEDIUM QUALITY TUBE	£10.69	£10.69	115.00	£1,229.35		
65MM MEDIUM QUALITY TUBE	£8.17	£8.17	150.00	£1,225.50		
50MM MEDIUM QUALITY TUBE	£6.05	£6.05	25.00	£151.25		
40MM MEDIUM QUALITY TUBE	£4.30	£4.30	16.00	£68.80		
32MM MEDIUM QUALITY TUBE	£3.73	£3.73	340.00	£1,268.20		
25MM MEDIUM QUALITY TUBE	£2.95	£2.95	345.00	£1,017.75		£7,463.25

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Figure 3 - Single Rack Sprinkler Layout

Figures 19, 22, or 25	Unexpanded Plastic	Any	Wet	10 (3.0)	100 (380)	11.2 (160)	6 on top IRAS level	No
				15 (4.6)	140 (530)	22.4 (320) Pendent	6 on top IRAS level	No
			Dry	10 (3.0)	100 (380)	11.2 (160) Upright	8 if one IRAS level or 14 (7 on top 2 levels)	Yes

Figure 22 - New tender referencing applicable rules. 41

3.2: Installation Strategy

This proposal and the preliminary timing plan detailed above are based upon certain site conditions being met, these include:

- // For a project of this duration and complexity TFIS would include for a visiting Site Supervisor.
- // Site Install works to be completed in one continuous visit, with clear and uninterrupted access to work areas as required, during our normal working hours, i.e. 8am to 6pm Monday – Friday (excluding Bank Holidays).
- // Our proposal has been based upon agreeing an installation sequence which will enable uninterrupted installation of protection within the racking/pick tower.
- // Key dependencies being complete and available to facilitate our works, these include:
 - Adequate Water Supply
 - Electrical Supply
 - Single Face Rack Construction to agreed schedule – 1/13 of the racking is to made available at any given time to allow for sequential working.

Figure 23 Installation Strategy from new tender proposal.....41

X - References

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