SEAMS
Building Analytic Capability

SSW: Water Infra Model Review

1562

Report

This document details the findings of the water infrastructure model review carried out by SEAMS Analytics for South Staffordshire Water.

05/07/2013

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1. Introduction

SEAMS Analytics have carried out an independent review of the water infrastructure model designed and configured by South Staffordshire Water (SSW). This report documents the findings of this review, provides a score by which SSW can benchmark future improvements and gives a number of conclusions and recommendations.

The focus of the review has been on the pipe burst element of the modelled system but consideration has been given to its interactions with other model components, for example the consequence model.

1.1 Analytics

The review has been broken down into the three key components of Analytics (descriptive, predictive and prescriptive), with a further section providing conclusions and recommendations. Analytics in Asset Management is a growing discipline and one that can provide water companies significant long term benefits, Figure 1 summarises the three different fields explored:

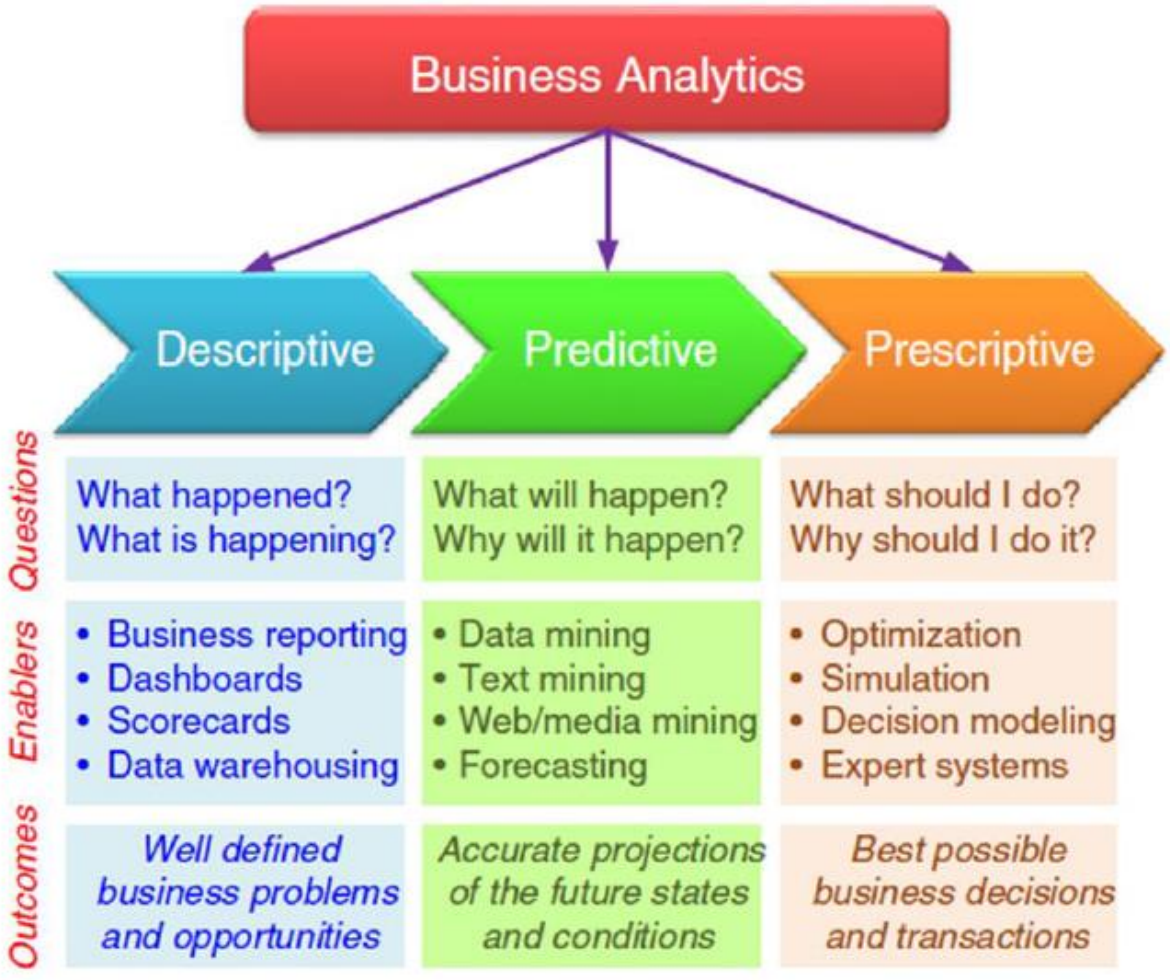


Figure 1 – Analytics Review

1.2 Score Summary

Table 1 gives a high level summary of the scores given throughout this review. The overall score was 5.8 which represent a sound analytical and modelling effort by SSW. Each field, type and item has its own sub section with more detail. A conclusion and recommendations are given in Section 5

Model	Field	Type	Item
Analytics (5.8)	Descriptive Analytics (6.5)	Data (6)	Assets (9)
			Performance (6)
			Interventions (5)
			Costs (4)
		Historic Analysis (7.5)	Serviceability Trends (7)
			High Level Analysis (8)
	Predictive Analytics (5.8)	Serviceability (5)	Bursts (8)
			Interruptions (3)
			Others (4)
		Risk (3)	
		Validation (7.6)	Burst Rates (9)
			Number of Bursts (9)
			Deterioration (8)
			Cross Correlation (6)
			Back Cast (6)
		Sensitivity (2)	
	Prescriptive Analytics (5.2)	Solver Method (6)	
		System (5)	Requirements (6)
			Ease of Use (5)
			Flexibility (5)
			Visualisation (4)
			Integration (5)

Table 1 – South Staffs Water Infra Model Score Summary

2. Descriptive Analytics

Important to understanding the water network is in analysing historic data to understand what has happened in the past. From such analysis it is possible to gain an understanding in historic failure rates and look for trends in the data.

To achieve this, data has to be collected from a number of disparate systems and its integrity should be explored. Before more predictive analysis takes places it is wise to understand the context upon which the model is being created, which often requires analysis of historic levels of serviceability. This is also aligned with the capital maintenance planning common framework (CMPCF) set out a number of years ago and still at the heart of a significant amount of OFWAT guidance.

This section reviews the descriptive analytic techniques employed for the water infra model:

- Section 2.1 – Data
- Section 2.2 – Historic Analysis

An overview of the scores for this section is given in Table 2. In summary, a relatively high score is given which represents the good quality data that SSW holds on their assets and bursts. The score is tempered somewhat by the data used in other model components, for example, costs and consequence. After discussions with SSW it was noted that in this first evolution of the model it was not designed to be all inclusive of many KPI and that this will be built upon in business as usual throughout AMP6.

Field	Type	Item
Descriptive Analytics (6.5)	Data (6)	Assets (9)
		Performance (6)
		Interventions (5)
		Costs (4)
	Historic Analysis (7.5)	Serviceability Trends (7)
		High Level Analysis (8)

Table 2 – Descriptive Analytics Score Overview

2.1 Data

This section reviews the data used within the water infra model. A breakdown is given by the key components of a model:

- Section 2.1.1: Assets
- Section 2.1.2: Performance
- Section 2.1.3: Interventions
- Section 2.1.4: Costs

2.1.1 Assets



In general, the asset data used for the model was excellent. All water infrastructure pipes are held on the GIS system (Strumap) giving ~6,000km of water network across ~200,000 pipes. The quality of the data has benefitted greatly from a digitisation project in the 1990's in which the original council records were analysed and used to populate any unknown asset attribute data. SSW noted that they have 100% population of all key attributes used within the model which includes:

- Pipe Type, Material, Diameter, Year Laid, Soil Type, System Zone

This is particularly impressive and provides a sound foundation upon which modelling can be carried out. When questioned on the validity of the attribute data it was noted that as SSW has remained as a single water company for many years, there has been no fragmentation of data through time which has therefore allowed for consistently high quality data.

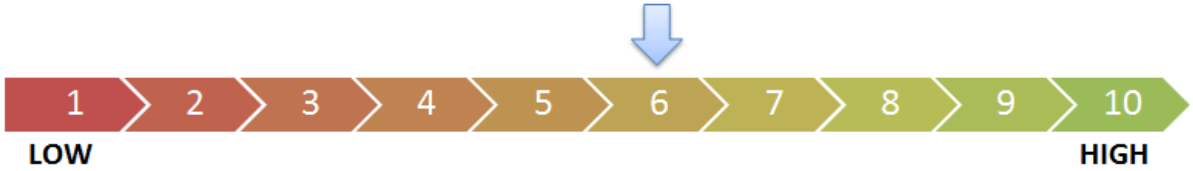
In most water companies, year laid is typically populated very poorly. Upon investigation of the age profile of the network it shows all the common traits expected such as the dips during war periods. There are some spuriously large outliers in the very old age bands which looks like some form of "default old ages" as it is unlikely such large amounts of length can have been installed during a single year. However, this is not uncommon and is not as pronounced as other water companies.

As SSW have had a relatively healthy ~1% pipe replacement programme for a number of years, coupled with a well updated asset system, the post 1980's pipe attributes can be viewed as exceptionally accurate.

There is some concern that data may be lost and/or not updated accurately during a transition from STRUMAP to a new corporate system (ESRI). Care should be taken during this process to maintain the validity and quality of the asset data to ensure accurate future modelling can be undertaken.

In summary, the asset data is excellent with only a few spuriously large year-laid points which look like defaults. It may be worthwhile doing a random sample of these pipes to investigate the age and validate/smooth out the default points. Due to the high quality of source systems, a high score of 9 is given to the asset data used within the model.

2.1.2 Performance



The quality of the performance data within the modelled system varies widely. At the one extreme, the burst data used is very high quality and has been interrogated in a fine level of detail. At the other extreme a single SSW average has been used for other KPI such as discolouration.

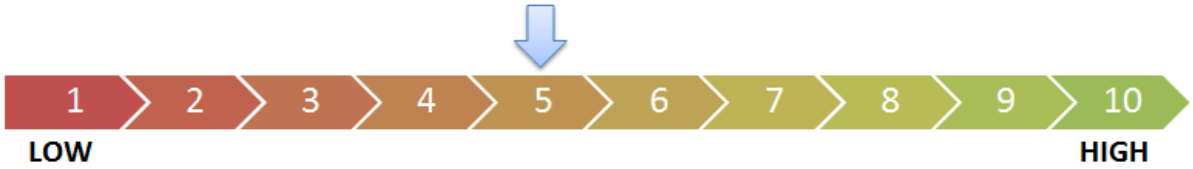
At the moment, the primary purpose of the model is to rank strings by the highest burst rate and generate schemes (using proximal pipes) for each year within a given pipe rehab length. For this purpose alone the performance data is more than fit for purpose.

The concern lies in the quantity and quality of data used in the consequence model, which appears more as a “bolt on” to the main model to ensure appropriate KPI are output for the IO tool. SSW no doubt hold a lot more complex and sophisticated data about interruptions/discolouration and making full use of this data into the future will significantly strengthen the consequence aspect of the modelled system.

It is recommended that all data related to consequence be reviewed and its possible use in advanced modelling/analytics be investigated, very much in the same way the burst data has been.

In summary, the burst performance data is excellent and is the heart of the current model. However, the consequence data used in the model is a concern so the score is tempered somewhat to 6.

2.1.3 Interventions



Interventions are critically important to any model. They provide the solution for the problems at hand. It is important that the model best reflects the interventions carried out on the ground without adding too much complexity.

As the model focusses on bursts then the only proactive intervention configured is that of pipe replacement. It is assumed that a new pipe will be laid (age=0) and that it will be replaced with HPPE (which has its own deterioration rate). This is an appropriate method to apply.

There are no operational interventions considered within the model. For example, other water companies will quantify the impact of pressure management on bursts which can be used as an alternative intervention. If discolouration was added into the simulation model then this could be controlled through flushing (which may have a negative effect on bursts).

In summary, for the current model the intervention applied is basic but fit for purpose. Any future evolution of the model to incorporate consequence into simulations would require additional thought and effort towards how different interventions would be captured within the model. As such an average score of 5 is given.

2.1.4 Costs



Costs typically make up an important component of a water-infra modelled system as they are usually built up as Whole Life Cost models. WLC models will have varying unit rates for proactive interventions such as pipe replacement dependent on material, diameter, surface type, etc. Furthermore, different size pipes will incur different amounts of reactive unit cost, whether that be fixing the burst or accounting for the overall cost of an interruption to a customer.

Simplistic Cost Model

The SSW model does not incorporate costs explicitly into the model. Instead a single unit rate for pipe replacement (£130) and a single rate for pipe bursts (£827) are applied outside the model before the data are passed into the IO tool.

In some regards, this level of simplicity is beneficial to the current model. The solver method applied ranks strings by burst rates within the prioritisation routine. As all strings have the same unit rate then this becomes a constant and therefore the cost benefit does not need to be calculated within the model.

However, in reality, this seems overly simplistic. For example, age regression relationships have been calculated and applied to materials with less than 0.1% of total length of the network, a level of detail far beyond that applied to the cost model.

It is highly recommended that a thorough review of the costs be carried out in the next evolution of the model and that a greater amount of granularity be applied. Adding cost into the model as a common currency becomes increasingly important if the model evolves to include multiple serviceability measures and SSW wants to run scenarios that minimise the WLC of the network.

Discount Rate

Another concern is the lack of a discount rate within the asset model. SSW note that this is accounted for with the IO tool but investment decisions made at this level should be cognisant of the impact of future prices on the investment decisions. To some extent, with the current prioritisation solver the discount rate will make no difference to the pipes selected but nonetheless it would prove beneficial to take account of NPV within the model at some point in the future.

Residual Value

A water infra model that makes a number of investment decisions between operational and capital investments (e.g. pipe replacement vs. flushing) will often continually select maintenance options as the cheapest way to maintain service. However, in doing this the overall value of the network is significant degrading through time. Adding residual value to the model will ensure that the long term benefits (beyond 40yrs) of capital replacement are more accurately reflected.

2.2 Historic Analysis

To develop a water infrastructure model requires analysis of historic data. To produce a predictive model of the future it is first important to understand the past. This section explores the analytics carried out by SSW to frame and understand the modelling problem at hand.

2.2.1 Serviceability Trends



It was noted by SSW that a monthly serviceability board report is produced which tracks key indicators over the past few years. These are not referenced in the analytics report supplied and it is highly recommended that they are included in future versions.

It is important to remember the key reasons why this water infrastructure model is in existence. It is not to simply create a better version of the last model. Instead it is to ensure that investment decisions being made are as optimal as possible to ensure best possible serviceability to the customers at affordable levels.

Through the review it is clear that SSW are putting customers at the heart of their decision making process. However, further work could be done to demonstrate how the models being used contribute towards this overall company goal. A score of 7 has been assigned.

2.2.2 High Level Analysis



Before finalising the analytical methodology for quantifying the probability and deterioration of pipe bursts, SSW reviewed alternative methods and carried out high level burst rate analysis by different attributes. This initial analysis helped determined the most appropriate methods to use and shows diligence in the model building process.

Whereas the current analytical report is clearly still in a draft form, it does describe a clear journey which helps frame understanding of the model. The only real criticism is that it would be worthwhile producing a “high level design” document which strips away all the technical aspects of the model and allows non specialists to understand the core concepts of the model. This document will prove useful when communicating the model around the business and to external stakeholders. A high score of 8 has been assigned.

3. Predictive Analytics

The SSW water infra model is primarily focussed on the probability of bursts. There is an "add-on" consequence application which is applied outside the model and multiplies the number of bursts by a given factor to produce predicted serviceability.

This section reviews the predictive analytic techniques used for water-infra serviceability, how/if risk has been captured and the validation/sensitivity of the methods employed:

- Section 3.1: Serviceability
- Section 3.2: Risk
- Section 3.3: Validation
- Section 3.4: Sensitivity

An overview of the scores for this section is given in Table 3. As expected, those elements of the model related to bursts scored very highly and indicated that the key components of the model are very well validated. The key concerns noted were around consequence KPI, Risk and Sensitivity but even with those issues the model scored a respectable 5.8 in predictive analytics.

Field	Type	Item
Predictive Analytics (5.8)	Serviceability (5)	Bursts (8)
		Interruptions (3)
		Others (4)
	Risk (3)	
	Validation (7.6)	Burst Rates (9)
		Number of Bursts (9)
		Deterioration (8)
		Cross Correlation (6)
		Back Cast (6)
	Sensitivity (2)	

Table 3 – Predictive Analytics Score Overview

3.1 Serviceability

This section explores and reviews the methodologies used within the model. The bulk of the review focusses on bursts which is the main KPI analysed and implemented. The burst regression lines for each of the materials are reviewed. Further discussion is given to the other serviceability measures in which less detailed analysis has been carried out.

3.1.1 Bursts



In general, the analytical work carried out by SSW is of a very high standard, utilises sophisticated tools and has explored a wide range of explanatory variables. A total of 42 regression lines have been created, using a mix of linear, power, log, exponential, inverse and constants. Care has been taken to select the most appropriate and accurate relationship, utilising engineering knowledge where appropriate. The analysis strikes a good balance between statistical accuracy and common sense around the known behaviour of water pipes.

Methodology Choice

The decision was made to utilise the regression analysis from SPSS as the basis of the model. The alternative method explored was applying material specific age regression analysis against the decommissioned assets only, thus removing the need to take account of the “rehab effect” explored within the SSW analytics document.

For now, the correct decision has been made. However, further investigation into this alternative methodology is highly recommended as the fit is very strong and clear, despite there being significantly less data to derive the relationships. An integrated method which takes into account past and future rehabilitation would be an on-going analytics study that would add value to SSW.

Weighted Regression

Throughout SSW analysis, care has been taken to ensure any age “outliers” were omitted from the analysis. For example, if a very small length was within a given age band then it was excluded to avoid it skewing the overall regression analysis.

As an alternative, any very small lengths (e.g. <1% of data set) could have been grouped into its nearest age band. Furthermore, a weighted regression (by length) would have been more appropriate to capture all data and ensure that each point is accurately represented. This is not a major issue but into the future it is recommended that the relationships are re-derived using this method and the difference analysed.

Pipe Attributes

A number of key asset parameters have been explored, including material, diameter, age and soil type (including corrosion levels and fracture potential). This provides a wide range of parameters that are traditionally seen as the key reasons for pipe bursts. One notable omission is that of pressure. It is often found that in high pressure zones there are higher burst rates and in low pressure zones, vice versa. If pressure data is available it would be worthwhile exploring the impact of this attribute.

Climate Change

The impact of changing weather conditions on the serviceability of the network has not been undertaken (at least not in the study reviewed). Investigation into the impact of temperature and soil moisture levels is likely to show some correlation with bursts. This would be difficult to build into the model as predicting future weather patterns is highly unreliable. However, such a study would have a number of uses.

It would allow SSW to better understand the number of bursts in previous years and could be used in conjunction with a back-cast analysis (Section 3.3.4) to explain the difference in modelled outputs versus actual from previous AMPs. Furthermore, it could be used to help promote operational efficiency by putting the company on alert in months identified as high risk of bursts.

Summary

In summary, the predictive analytics carried out for bursts is excellent. A wide range of analytical techniques have been explored and reasonable rates of deterioration have been applied. There are a number of improvements that can be made but overall a high score of 8 has been achieved.

3.1.1.1 HPPE

Due to a lack of data, a number of UK water companies would apply an assumption that a new HPPE pipe will not deteriorate throughout the life of the model. However, SSW have quantified the “burn in” phase of the new material and then applied a simple linear deterioration to cross over at 50 years to account for the typical life cycle of a water pipe. In principle this is sound even if it does lead to a self-improving network. In general, the burst rate of HPPE is so low compared to the other materials that any inaccuracies in these regression lines are likely to be inconsequential to the model outputs (albeit sensitivity would prove this).

3.1.1.2 AC

In principle, the approach taken for AC deterioration appears sound. There is very little evidence to show a correlation with age and therefore taking the mean failure rate is appropriate. A discrepancy has been found between the relationships within the model (for regression id 7 & 8) and that wrote up in the analysis notes. Linear relationships have been applied whereas the analytical notes state that a mean value of 241.17 and 377.56 would be applied, respectively.

These linear relationships are leading to 1.62% deterioration per annum of the whole AC material class, making it the 3rd fastest. Upon questioning, SSW noted that new relationships were derived but not included in the write-up, these are to be added in future versions.

3.1.1.3 DI

A single logarithmic curve has been used to quantify the rate of deterioration of ductile iron. The analysis does support this and once again is likely to be due to the "burn in" of the material in the early part of its life cycle. The analysis notes state that a constant of 39.448 will be applied after 21 years (to take account of the material getting to the bottom of its "bath-tub"), but this has not been applied in the final model.

Analysing DI in isolation, this has a significant impact, particularly over a 40+ time horizon. This gives a -1.45% per annum deterioration rate for DI throughout the 40 years. This leads to the number of burst halving which feels somewhat counter-intuitive. It is recommended that the constant after 21 years is applied to cap off this negative deterioration and would be more reflective of the material moving out of its "burn in" stage and into a more stable part of its life cycle.

That said, DI pipes account for less than 1% of total predicted bursts and as such this issue is likely to have a negligible effect on the overall model accuracy.

3.1.1.4 MDPE

There is very little burst data to analyse so determining age relationships is very difficult. A thorough analysis has been undertaken with a number of techniques applied and sense checked against engineering logic. The resultant regression lines lead to a 3 stage model which represents the burn in phase followed by a steady state and then a linear deterioration (same as HPPE). Given the lack of data, whereas not 100% statistically robust, this approach is reasonable and sound.

3.1.1.5 Steel

On its own, with the application of the 3 regression curves, Steel is the 2nd fastest deteriorating material. However, it only accounts for <1% of all predicted bursts so its significance in the overall model is small. A thorough analysis has been taken and the relationships applied are sound. However, it would have been equally acceptable to have used constants for this material as the relationships have a great deal of scatter.

3.1.1.6 mPVC & PVC

mPVC accounts for less than 0.5% of the predicted bursts and is applied a mean rate of 45.379. Given the insignificance of this material to the model this approach is acceptable.

There are very clear relationships between age and bursts for PVC. A total of 8 regression lines are produced for PVC dependent on the diameter and fracture potential. Given the data available, all relationships applied are reasonable and statistically robust for use in a strategic model.

The application of these relationships leads to a significant amount of deterioration on PVC pipes through time. This material is by far the fastest deteriorating with an increase of 3.84% in bursts per annum. Over 40 years this sees an increase from 134 bursts to 394 bursts.

For investment decisions this poses an interesting question. If the relationships are to be believed then it would be cost efficient in the long run to replace some of the PVC pipes sooner rather than later before they fail. This is explored more in Section 4.

3.1.1.7 CI

Cast Iron represents over 75% of the predicted bursts within the model, has one of the largest overall failure rate and the greatest proportion of network length. This provided a very large dataset for SSW to analyse and this resulted in 16 different regression lines.

SSW identified a clear difference between pre and post war cast iron materials. The change point for this model is 1952 which is similar to that seen in other UK water companies. The separation of data either side of this year is sound practice.

The general trend of smaller diameter pipes bursting more frequently was also found which led to a further branching out of the data. As expected, in most cases the smaller diameter pipes had a higher probability of blockage. The branching by diameter is sound practice.

Finally, it was found that increased fracture potential was a significant parameter, which is represented in the model via a given soil type. Other water companies have seen a correlation between high corrosiveness and burst rate so, as mentioned in the analytics report; it is likely that these two parameters have some correlation. It was surprising to not find a direct correlation between soil corrosiveness and cast iron burst rates but the mechanism used (fracture potential) gives confidence an effect is captured and modelled.

FINAL VERSION UPDATE: Further clarification from SSW shows that the final models used a factor reduced high / low corrosion for use in the model which is more in line with expectations from other models in the industry.

There is a slight concern that the form of the regression lines for post war cast iron pipes would give potentially inaccurate negative failure rates. Upon validation only a single string (343724) produced a negative burst rate due to a year installation of 2004. Upon query this was noted as a potential GIS data error. As this is a very small length string it has little impact on the overall accuracy of the model. However, it is recommended that any CI installed 1990 onwards be investigated to ensure the correct material is assigned in the source data and if so, that the age bounds of the regression lines are valid for the newer ages.

It could be argued that a few of the regression “bins” have a great deal of scatter and that there may have been too much branching of data. However, given that CI has the most length and the highest burst rate, the number of regression lines produced is acceptable.

3.1.1.8 Others

The other materials make up a relatively insignificant proportion of the total network. As such, these have been applied a single failure rate of 45.379 throughout time. This approach is acceptable.

3.1.2 Interruptions



The number of interruption events and properties affected is calculated outside the main model via the use of an "Other Values" worksheet. This acts as a look up table in which each system zone has:

- 0-3 hours, 3-6 hours, 6-12 hours, 12-24 hours, >24 hours
    - Frequency Per Burst
    - Number (Properties) Affected

Once the number of bursts has been predicted (pre or post investment) then a simple multiplication against this lookup table will produce the predicted number of interruptions within each system zone (SZ). Values only vary by SZ in the 0-3 and 3-6 categories, for the other categories a single value was applied. This is a relatively simplistic view of the way interruptions occur on the network, which only explores SZ as a variable that impacts the probability of interruption and affected customers. For the future, it is recommended that more sophisticated analysis be carried out.

In most cases, larger diameter pipes have both a higher probability of causing an interruption event and will impact more customers. If investment scenarios are asked about "maintaining or reducing" DG3 events into the future then a different mix of pipes would be needed than that of controlling bursts. A pipe that is very efficient for bursts is not always the most cost efficient for interruptions.

It was noted by SSW that it is the job of the IO tool to explore the impact on interruptions. However, the IO tool will only optimise the package of schemes that it has fed into the system. Currently this is a selection of SZ wide schemes for 40 years, all of which are prioritised to give the best possible returns on bursts for a given pipe replacement length. Furthermore, these sorts of asset investment decisions should be made in the asset modelling tool as they require asset level information.

This is one of the key concerns of the model but there are a large number of potential future changes that would mitigate/remove this concern. It is first recommended that more complex analytics be carried out around ascertaining the impact of different diameters on the probability of a burst leading to an interruption (across the different bands). Analysis of hydraulic models can also help quantify the expected number of properties that would be affected.

There are two different directions that can be taken to incorporate the new interruptions analytics into the model. The first seems most appropriate for the SSW model which would involve the creation of an overall risk score (more details available in Section 3.2). The alternative is to place constraints on both bursts and interruptions in simulations but this would require changes to the type of solver used within the modelled system.

Given the relative importance of interruptions within the water infrastructure, a relatively low score of 3 has been given for this KPI but with future improvement this can be resolved.

3.1.3 Other



As with interruptions, very simplistic analysis has been applied to other consequence and serviceability measures within the network. There are too many possible enhancements to the model to document here but it is recommended that future versions of the model consider more complex analysis on a wider range of KPI.

Using the customer's willingness to pay studies to prioritise which measures are most important will allow a focus to be placed for future improvements. That said, Interruptions are typically the most important KPI and therefore a slightly higher score of 4 is given.

3.2 Risk



Risk is typically defined as a function of both probability and consequence. In terms of the water network this is slightly more complex given the primary and secondary nature of serviceability measures within the network.

For example, there is a probability that a pipe will burst, which is extensively covered within the SSW model. Once a pipe has burst, there is also another probability that a consequence event will occur. For example, not all burst pipes will lead to a flood of a customer's home.

It is highly recommended that a suite of probability and consequence KPI be configured within the SSW model. However, this poses a significant problem when looking to prioritise investment, as you can no longer simply rank by burst rate.

For example, a certain system zone may have a significantly higher number of customers interrupted per burst (e.g. an urban area vs. a rural area). A pipe with a POF of 1000 that bursts in a low consequence area is likely to be less risky than a pipe with POF of 980 in a high consequence area, except the prioritisation will invest in the lower risk pipes due to the higher burst rate.

There are a number of modelling methods that can be employed to overcome this. The first is to move to a different solver such that you can put constraints on multiple performance indicators and therefore allow the optimisation solver to find the optimal mix of investments. The second is to combine all the probability and consequence models into a single risk score.

The first option requires configuration of a model using a decision support tool and will gain maximum investment efficiencies. The second option requires the creation of a risk algorithm which outputs a composite risk score that can be used as the new prioritisation rank.

Currently, the SSW model does not explicitly include consequence KPI within the simulation process so the first and most important step is to get them included. From here, either of the two options above can be considered to allow for more sophisticated investment scenarios that consider the whole risk of the network. On the plus side bursts are key components of risk and the consequence is calculated outside of the model before it goes into the IO tool. A score of 3 is given.

When this was discussed with SSW it was initially noted that the IO tool was to balance the consequence measures to give an optimal level of investment for all KPI across SSW. However, the IO tool can only balance options that have been supplied to it. If none of those options are optimal for interruptions and are carried forward as 40 year packages of work for a given SZ then it can merely select the combination that is least non-optimal. This is why the job of creating optimal asset investments for a specific asset class should be carried out in a model that holds asset information.

3.3 Validation

Validation and verification is a key part of any modelling system. From discussions with SSW there has been evidence to show that the importance of V&V has been recognised throughout. This section provides an independent review of the model validation.

To be as thorough as possible in this validation exercise, the input data and SQL queries that form the building blocks of this model have been recreated in specialised modelling software. This has allowed validation at a "string" level to ensure the modelled system in place is producing expected outputs from the analytics carried out. The validation areas were:

1. Burst Rates
2. Deterioration
3. Cross Correlation
4. Back Cast

3.3.1 Burst Rates



Once the model was recreated, the burst rates of all strings were analysed to look for any spurious predicted values. The predicted rate in time-step 0 as well as the last time-step was analysed to look for any potential issues in the deterioration rates derived within the regression analysis.

In general, the burst rates being produced by the model for the vast majority strings is reasonable and within the expected range for the given material. There have been a few minor discrepancies found at the extremes of the model. As such, an excellent score of 9 is given.

Negative Burst Rate Check

Within the validation model all 37,863 strings were interrogated for any negative burst rates at both time-step0 and time-step42. Only 1 pipid produced a negative rate at T0 and that was 343724. Upon discussions with SSW it was noted that this was an incorrectly labelled pipe as CI when it should have been DI due to a meter bypass on a run of pipes. SSW noted that there is a potential for 38 further strings to be impacted by this data issue and it is recommended that these are updated for the next data refresh of the model.

After 42 years, due to the deterioration quantified in the model then a further 3 strings give a negative burst rate, these are 1028933, 3975587 and 302341. These are all very old DI pipes (laid circa 1900) and are due to the inverse relationship discussed in Section 3.1.1.3. Either applying constant deterioration after 20 years or putting a validation check in the code to ensure no negative rates is recommended. That said, it doesn't make sense that a 100yr old DI pipe will have no probability of failure but a 20 year old pipe will have a higher probability. Some deterioration mechanism to reflect the life cycle of this material would be an alternative.

Extreme Burst Rate Check

A similar check was carried out but to look for any spuriously high burst rates. In general, this check produced no widely inappropriate burst rates but there was concern a very small percentage of the pipes have significantly higher than mean burst rates.

Across the entire network the weighted average (by length) string probability within the model is 184 bursts per 1000km. A very small proportion of pipes have a predicted burst rate in excess of five times the average, these are all very old, small cast iron pipes. These rates get as high as 1 burst every km which is acceptable but still a little questionable.

Figure 2 has been produced which shows the distribution of average burst rate (a running 30 string average ranked from highest to lowest), set against the associated length of the network. It can be seen that there is a great deal of variation in burst rates across the network which typically means that high levels of efficient investments can be made (as you can target the worst performing for maximum returns). Please note this chart was created from T0 burst rates.

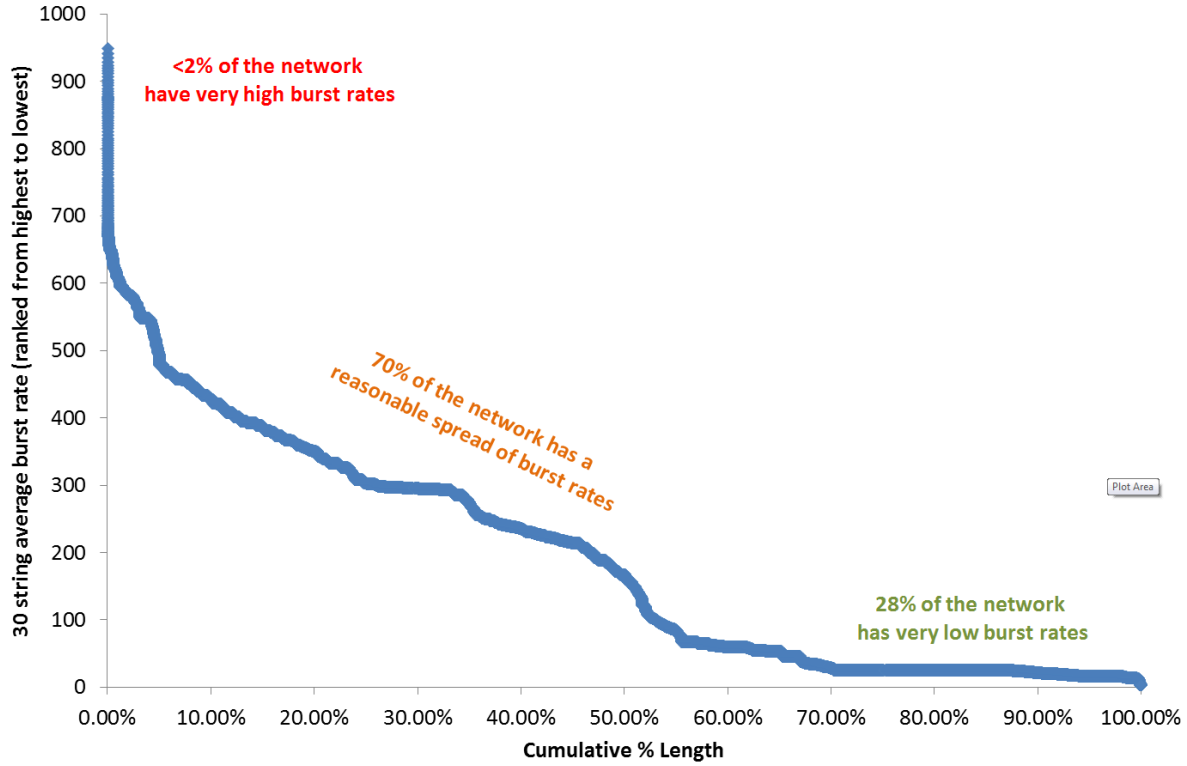


Figure 2 – Burst Rate Variation (T0)

In carrying out this analysis, it was also noted that some plastic material groups had year installed dates prior to 1960, some as far back as 1905! Whereas this represents only 1km of pipe and has little overall impact on the model, it does indicate that more validation checks on the base asset data is required to remove any obvious errors (i.e. materials existing before they were invented). Adding these validation checks into the SQL should be a relatively easy task.

3.3.2 Number of Bursts



The calculated burst rate for each string is multiplied by the length to give the predicted number of bursts. This can be aggregated and analysed. A number of sense checks have been carried out to ensure the model in use by SSW is correctly calculating the number of bursts and that the application of the age regression in the model is appropriate.

Figure 3 shows the aggregated number of predicted bursts in both the validation model produced by SEAMS and the actual model outputs provided by SSW. It can be seen that throughout the 42 years there is <1% difference which gives confidence in the accurate coding of the SSW model.

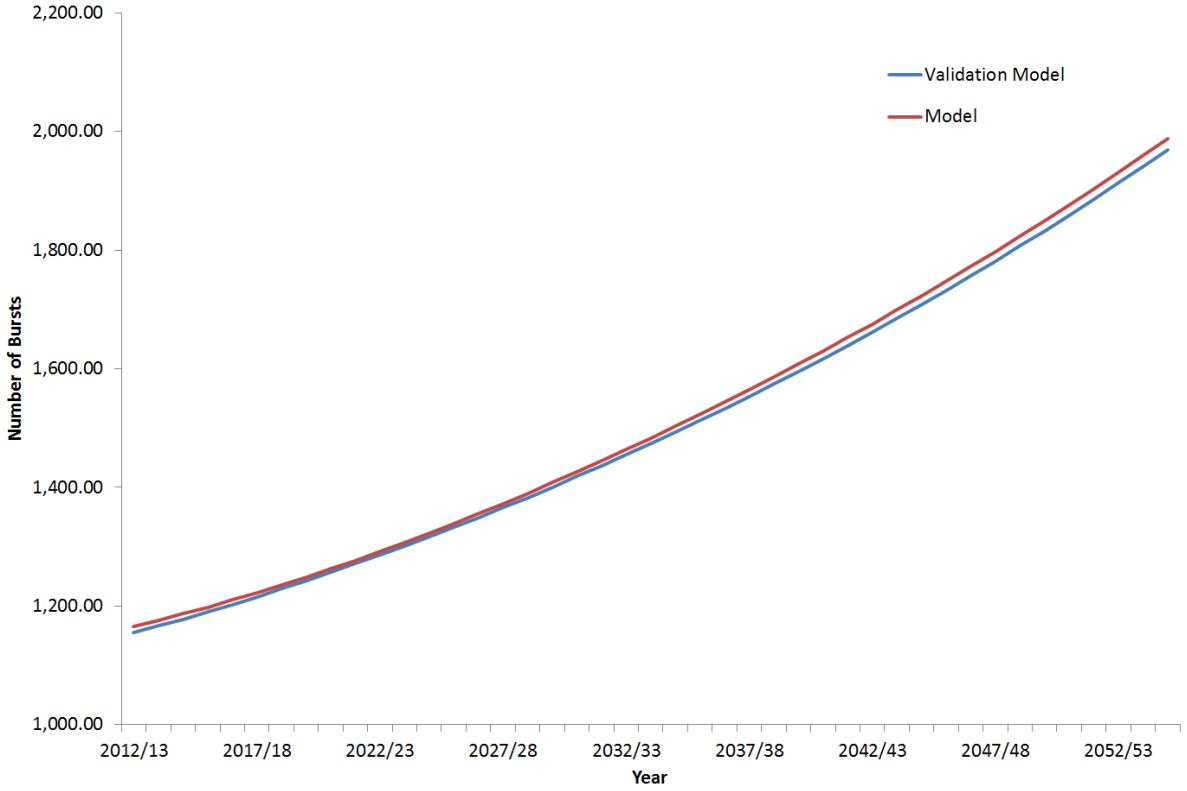


Figure 3 – Number of Bursts (Actual Model vs. Validation Model)

During the review, there was some uncertainty regarding the starting number of bursts to use within the model and what is an appropriate start year. The IO tool, which the output of this model feeds, has a starting date of 2015 so outputs from T2 onwards (2015+) are supplied. This does mean that in the IO tool there will be a different starting number for different scenarios, as varying amounts of pipe rehab will have taken place in T0-T2 impacting the starting burst number of 2015. SSW should be confident that varying start numbers are acceptable for use in the IO tool. Alternatively calibration factors should be applied to ensure a consistent start number.

Technically, a 1% difference in the validation and actual model is outside the scale of what you would expect (potentially for rounding differences in the systems used). It is likely that the two versions of the model have slightly different applications of the age regressions. To fully explore the reason for this discrepancy is outside the scope of this review and therefore the <1% margin was deemed suitable for the purpose of this review and a score of 9 was given.

Bursts by Material

Figure 4 shows the distribution of bursts across the different material groups. It can be seen that CI dominates due to this material accounting for the vast majority of the network and it has a relatively high burst rate. PVC is the next largest contributor and AC the third. Given the burst age regression relationships derived, this was as expected.

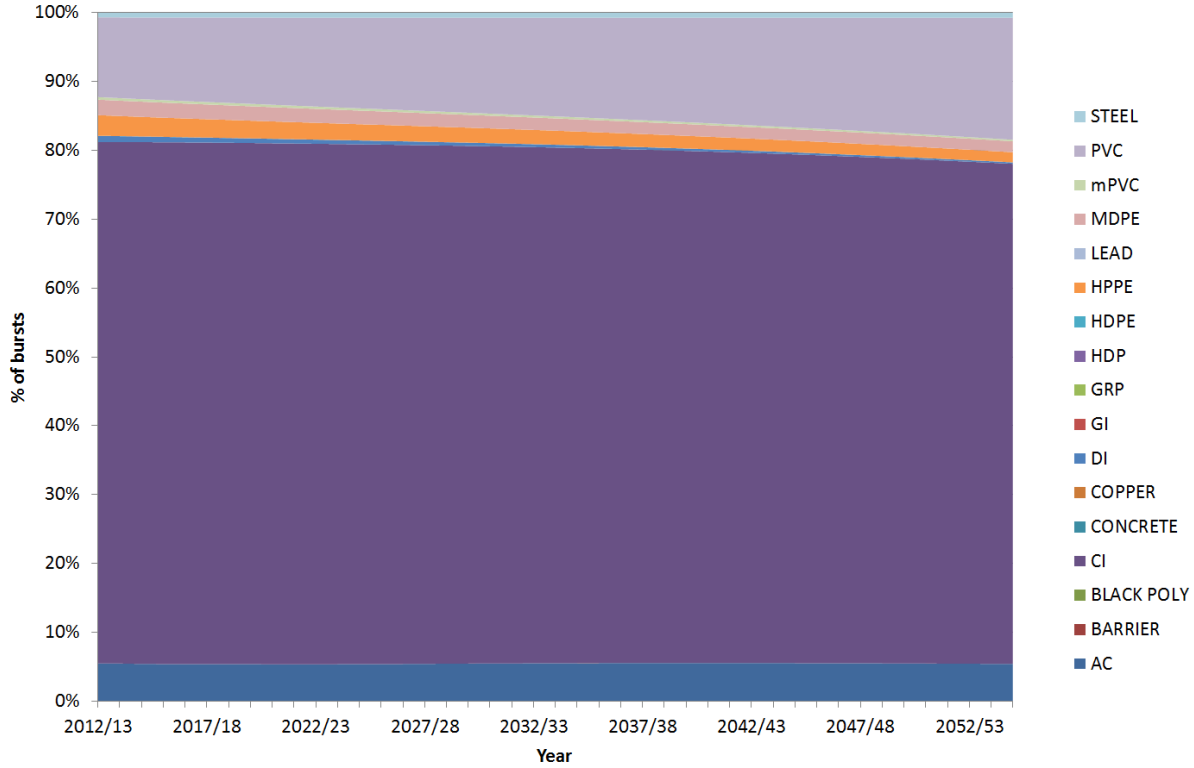


Figure 4 – Percentage of Total Bursts by Material

It is of interest that the vast majority of the materials contribute a relatively insignificant amount of bursts to the overall model. There may be scope to rationalise the number of materials held within the model in future evolutions. By having less material groups this may allow additional complexity to be added (e.g. interruptions, discolouration, risk, etc.) without compromising too much on the speed of simulation solves.

Bursts by other attributes

A number of other sense checks were carried out by aggregating bursts by diameter, year-installed, soil type and system zone. No obvious errors or discrepancies were found. However, it is highly recommended that the interrogation of the output data become part of the business as usual modelling process that SSW undertake.

3.3.3 Deterioration



Every time-step of the model the strings will age by 1. This new age is then processed through the regression equations to generate a new burst rate, which then gets multiplied by the length to predict the number of bursts. As previously shown in Figure 3, in a do nothing scenario the number of bursts will increase from 1155 to 1970 bursts throughout a 42 year time period. This equates to ~1.68% deterioration per annum and the validation model is within 1% margin of the actual model.

SEAMS typically find burst deterioration rates of 1% per annum so the SSW value of ~1.7% is higher than usual. However, the age regression analytics is robust so there is no reason to be overly concerned. As such a score of 8 is given. That said, further investigation as to why SSW feel their network would deteriorate faster than typical would be a worthwhile exercise.

Burst Rate Variation over time

Figure 5 is a recreation of Figure 2 discussed earlier but an additional line has been included which represents the burst rate distribution after 42 years. It can be seen that due to the rates of deterioration on some strings, the variation of high to low rates increases significantly.

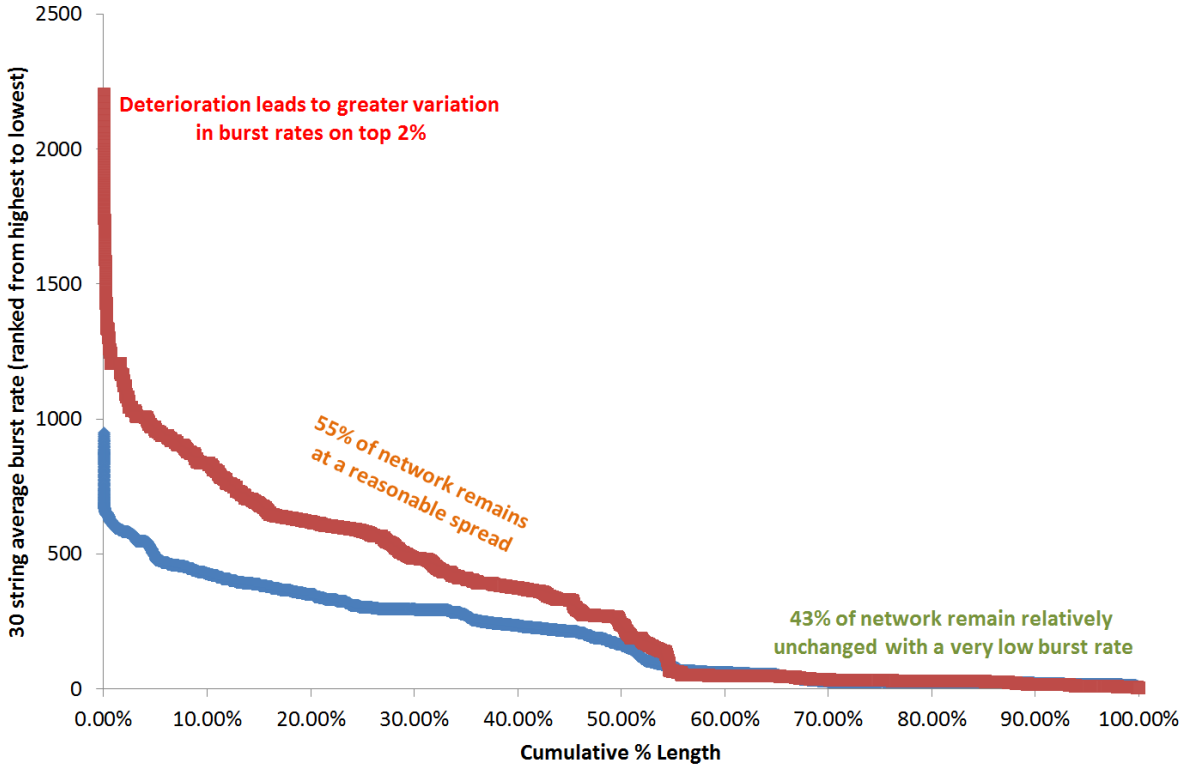


Figure 5 – Burst Rate Variation (T0-Blue vs. T42-Red)

Burst Deterioration by Material

Table 4 shows the predicted number of bursts by material at the start and end of the model. The most important deterioration rates have been highlighted in red and green. CI accounts for the majority of the bursts and deteriorates one of the fastest. ST is second fastest but relatively insignificant. AC is third fastest at a similar rate to CI. This is all acceptable.

Of most interest is the rate of deterioration of PVC, which is very much driven by the older PVC pipes already in the network. Over 40+ years this material becomes an increasingly major contributor of bursts throughout the network and by the end of the 42 years, on average; it has the highest burst rate of all the materials (overtaking CI).

Material	Bursts T0	Bursts T42	Avg. Deterioration
AC	**63.27**	**106.21**	**1.62%**
BARRIER	0.01	0.01	0.13%
BLACK POLY	0.00	0.00	0.00%
CI	**874.80**	**1431.07**	**1.51%**
CONCRETE	0.01	0.01	0.00%
COPPER	0.00	0.00	0.00%
DI	**10.32**	**4.02**	**-1.45%**
GI	0.02	0.02	0.00%
GRP	0.00	0.00	0.00%
HDP	0.01	0.01	0.00%
HDPE	0.14	0.14	-0.08%
HPPE	34.60	28.94	-0.39%
LEAD	0.00	0.00	0.00%
MDPE	26.06	31.35	0.48%
mPVC	4.28	4.28	0.00%
PVC	**133.80**	**349.41**	**3.84%**
STEEL	7.70	14.05	1.96%
TOTAL	**1155.03**	**1969.54**	**1.68%**

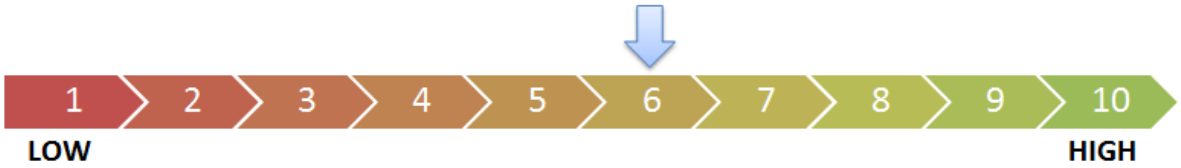
Table 4 – Deterioration Rates by Material

From a “model coding” perspective, the deterioration rates by material are all as expected and accurately reflect the age regression analysis produced. This gives confidence the model is a fair reflection of the analytics carried out.

There was some concern with the -1.45% deterioration rate per annum for DI. However, as noted in Section 3.1.1.3, without a cap on the inverse relationship then this was to be expected. It is recommended this is reviewed as it can lead to 100 year old DI pipes that have a lower probability of bursts than a 20 year pipe, which appears counterintuitive.

The main concern of the deterioration in the model is the speed at which PVC fails through time. Moreover, it is this coupled with the solver method (prioritisation, year on year, of the highest burst rate strings) that could lead to temporally inefficient investment decisions. If the PVC rate of deterioration is robust then there is a case to replace PVC sooner rather than later, proactively before the rate of failure increases to the highest levels.

3.3.4 Cross Correlation



One of the concerns of modelling such as that carried out at SSW is that the regression relationships found can be biased by the impact of cross correlation. For example, if all old pipes were typically small pipes, then what appears to be an age relationship could in fact be consequential to the cross correlation of two parameters.

From review of the analytics report, cross correlation is touched upon and SPSS has been used to create a matrix of some of the key parameters used within the model. Importantly, there appears to be no obvious diameter/age correlation. That said, this analysis has been done at a very high level and as such a medium score of 6 is given.

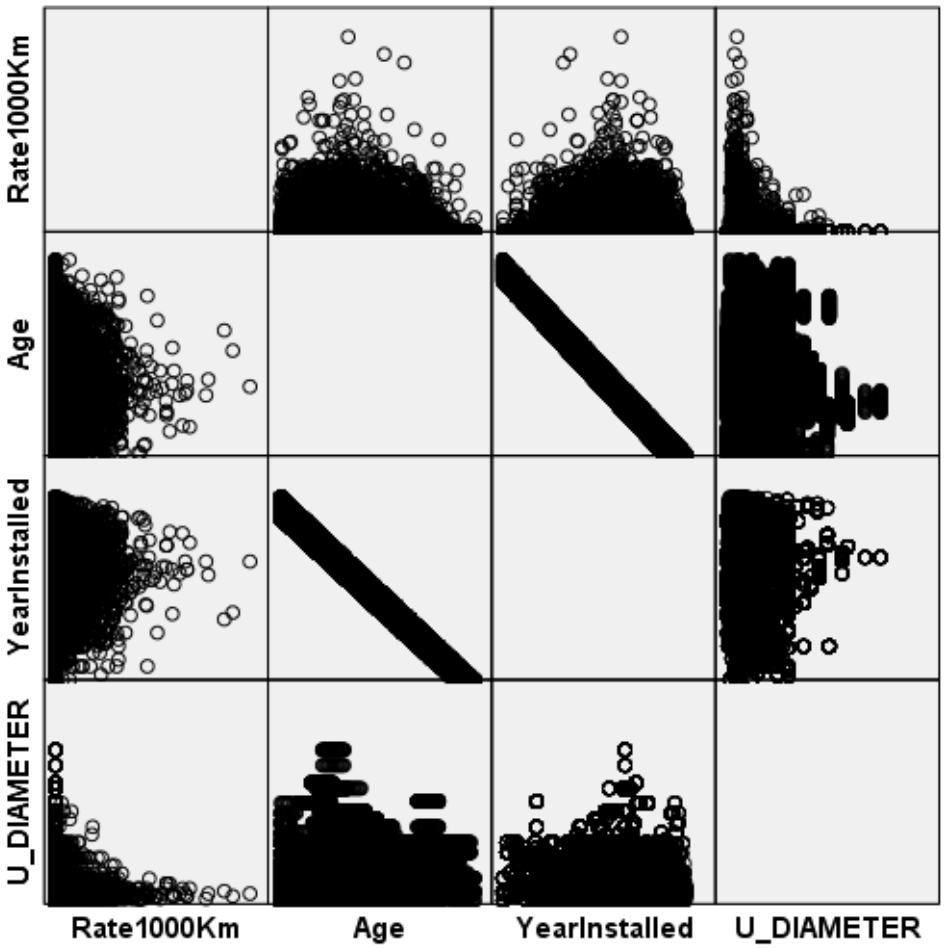
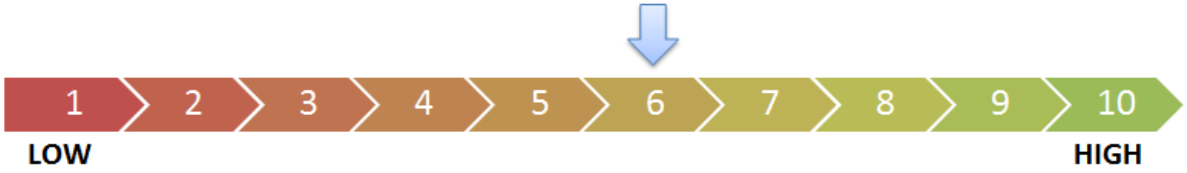


Figure 6 – SPSS Cross Correlation Analysis

Beyond the current analysis, there are a number of statistical methods that can be employed to analyse and quantify the impact of cross correlation across all attributes on the network contributing towards bursts. This should not be a priority but it is recommended for the future.

3.3.5 Back-Cast



A validation technique commonly requested by many auditors is the “back cast”. To achieve this the network has to be “winded back” to a point in time (typically 5 years ago) by undoing the interventions already carried out on the network and creating a new base asset file for the model. From here the starting number of bursts is calibrated to the actual starting number and the model is run for 5 years. Constraints are applied to restrict the amount of investment that can be done by the actual £ or km done each year. The modelled outputs are then compared to the actual outputs and the differences reviewed.

SSW has done some forward projections of historic trends set against their current and future expected rate of rehabilitation. This gives some confidence that the amount of investment being requested for PR14 aligns with their strategy for reducing bursts into the future. However, a full back cast validation as noted above has not been carried out and therefore a score of 4 is given.

It should be noted that the expectations of this validation is not that the model will predict exactly the same as the actual. In fact, if it did the results would be even more questionable. The act of going through this exercise is a challenge to the processes of the company as regards:

1. Has historic investments been recorded on the system and if so does the company know which pipes were replaced and in what year?
2. Is the cost of the historic investments recorded?
3. If (when) the modelled outputs do not match the actuals, what other reasons not captured in the model could be the cause (e.g. weather, strategy not matching delivery, etc.)

It is recommended that this exercise is undertaken but the use of its outputs should be carefully communicated as to avoid wrongfully critical analysis of the model from people who do not fully understand the outputs.

FINAL VERSION UPDATE: Upon discussion with SSW, a first attempt at back cast has been carried out and documented in the v3 model documentation. As such, this score has been increased to 6 and it is recommended that the back cast be expanded to include additional KPI as they are added to the model through time.

3.4 Sensitivity



Having a robust and comprehensive sensitivity study carried out on a model is a critical part of the modelling process. The key benefits from such analysis are:

- Quantification of the current base investment programme robustness
- A list of the most sensitive parameters within the model
- A greater understanding as to where to focus future data improvements
- Increased level of validation, quality assurance and confidence in the model

As of the time of this review, limited sensitivity analysis had been carried out by SSW but it has been prioritised as a key action for the future. As such, the model currently scores a low 2 but this can be easily remedied by carrying out the sensitivity analysis.

To support SSW in this process, a typical method for sensitivity is described below for an anonymous water company in the UK. Figure 7 presents the stages and high level activities to be completed. A similar approach on the SSW model is highly recommended.



Figure 7 – Typical Sensitivity Project

00_Approach Design

The initial stage would be to engage with the model's key stakeholders and specify the project approach. Meetings are held to discuss the different options; the outcome of which is the agreement of the outline approach. The remainder of this stage would be to define the process to be followed in further detail. This would be achieved through a technical workshop and subsequent process documentation.

The underlying requirement in this area is OFWAT's question (#6):

- Expose the assumptions behind your plan and the sensitivity to those assumptions
- How have the assumptions been tested?
- What effect did they have on your decisions?
- How will you manage uncertainty during the AMP?

01_Parameter Identification

The model has a number of parameters that could be tested; the purpose of this stage is to identify and filter the areas/assumptions within the model to be tested. Figure 8 presents the scenarios considered by another major UK water company. The current SSW model would be more focussed around the age deterioration parameters (similar to W6 and W7 below).

Ref	Description
W1	Increased Cost of Electricity
W2	Reduced Cost of Electricity
W3	Altered Headroom Targets
W4	Remove Amenity S&E costs
W5	Removing all Social and Environmental costs
W6	Age-burst relationship more deterioration
W7	Age-burst relationship less deterioration
W8	ALC - Lower Policy Minimum
W9	ALC - Effectiveness Improvement
W11	NRR Growth - Age Relationship
W13	Demand - Housing Growth Forecasts
W14	Remove Climate Change Effects
W15	Reduce Outage

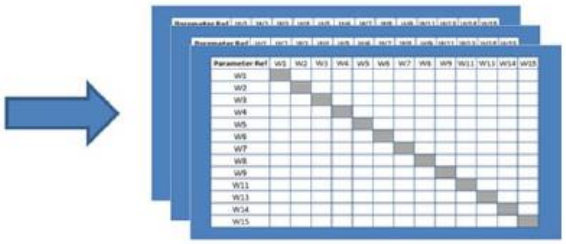


Figure 8 – Example Parameters

02_No Investment Sensitivity

Once the list of model parameter tests has been identified, the first set of analyses that will be required will be investigations into the variations in the input data, relevant to the parameter tests. For each parameter/assumption to be tested, a probability distribution needs to be established. These distributions would then feed into and be perturbed in a Monte Carlo analyses (Figure 9).

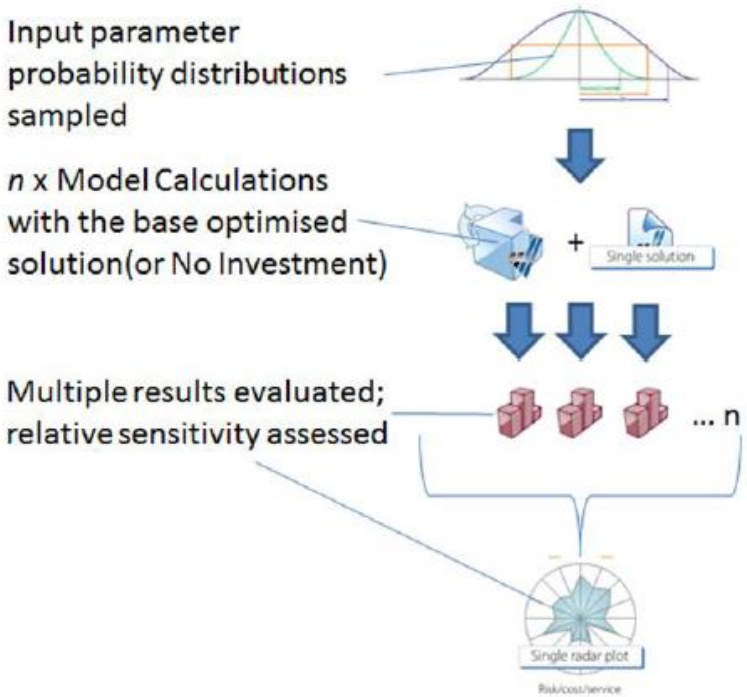


Figure 9 – Example no Investment Sensitivity Analysis Process

03_Solution Robustness Testing – Monte Carlo Simulations

Monte Carlo analysis is a statistical theory based on finding trends in large numbers of seemingly unconnected random events. We can simulate this by applying a distribution – such as a statistical normal distribution, to the input parameter(s) and calculating the effect of those. Multiple parameters can be evaluated in one pass, and the resultant model outputs form a population that can then have further statistics performed upon it. The key principles of this process are illustrated in Figure 10.

After many iterations of the simulation (typically thousands), of the Monte Carlo algorithm have been calculated, the resultant WLC, or other selected metric can be statistically analysed to give confidence in the output – for example "We will need to spend £10million on OPEX +/- 5%". Alternatively, the Monte Carlo can be used to evaluate the level of robustness around the serviceability levels that SSW will achieve for a given proactive investment budget (e.g. we expect to reduce bursts by 10% with a +/- 5% tolerance.

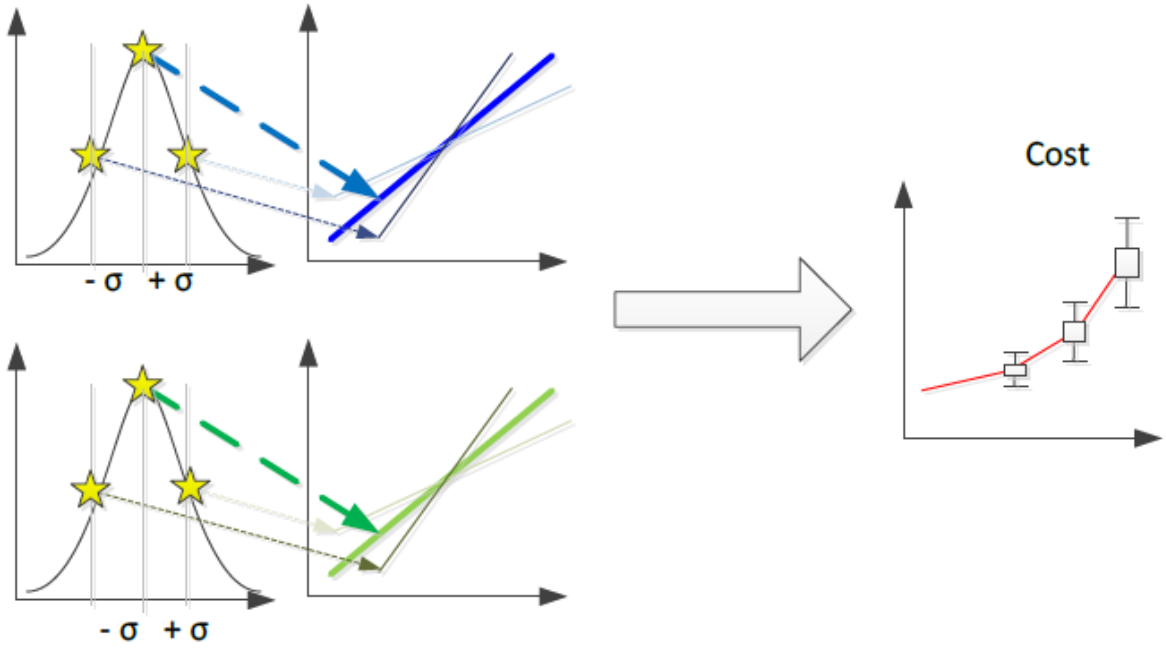


Figure 10 – The key principles of Monte Carlo

04_Model Re-optimisation

Once the robustness of the base solution is understood, it is proposed that a few focused model optimisation analyses are carried out, to assess the impact on the decisions made in the solution to perturbations in the most sensitive parameters of the model.

4. Prescriptive Analytics

Prescriptive analytics is the third generation of analytics and is a relatively new concept. In descriptive analytics we are analysing the past, with predictive analytics we are predicting the future but with prescriptive analytics we are using all this information to find the best course of action for a given situation. In short, prescriptive analytics is about making decisions.

For the SSW model this includes the solver method created within SQL and the ability of the modelled system to run different investment scenarios. For example, SSW may ask the following different questions of the model:

- What are the best returns on service if we want to replace 100km per annum?
- If we have to cap our budget to £5m per annum, how low can we get our bursts?
- To maintain our current levels of serviceability, how much do I need to spend?

This section reviews the prescriptive analytic techniques employed, including:

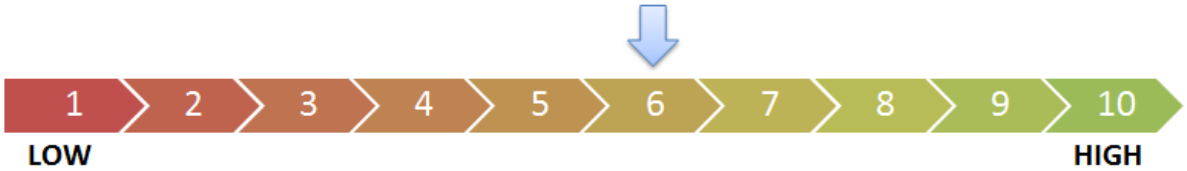
- Section 4.1 – Solver Method
- Section 4.2 – System Requirements

An overview of the scores for this section is given in Table 3. Nearly all scores are in the range 5-6 with an overall average of 5.2. For a relatively new model this is a very good score and represents a sound effort by SSW. For its current purpose the decision making within the model gives reasonable outputs and has been well validated. There are more complex solver methods and there are a number of initial requirements that were not met but SSW are aware of this and rightly prioritised key model components for PR14, with an improvement plan set for AMP6 and beyond.

Field	Type	Item
Prescriptive Analytics (5.2)	Solver Method (6)	
	System (5)	Requirements (6)
		Ease of Use (5)
		Flexibility (5)
		Visualisation (4)
		Integration (5)

Table 5 – Prescriptive Analytics Score Overview

4.1 Solver Method



The choice of solver for a water infrastructure model can have a significant impact on the predicted level of investment needed into the future. Using a relatively simple solver for a complex model can lead to inefficiencies both in the assets chosen and the years upon which it is selected. The modeller should be aware of the different solver methods available and select the most appropriate.

Figure 11 summarises the different solver methods. For the SSW a prioritisation has been used in conjunction with some additional investment decision logic. This current version of the model is very much dominated by a single KPI (bursts) and in such models the chosen methodology tends to be the most appropriate and fastest way to find a solution.

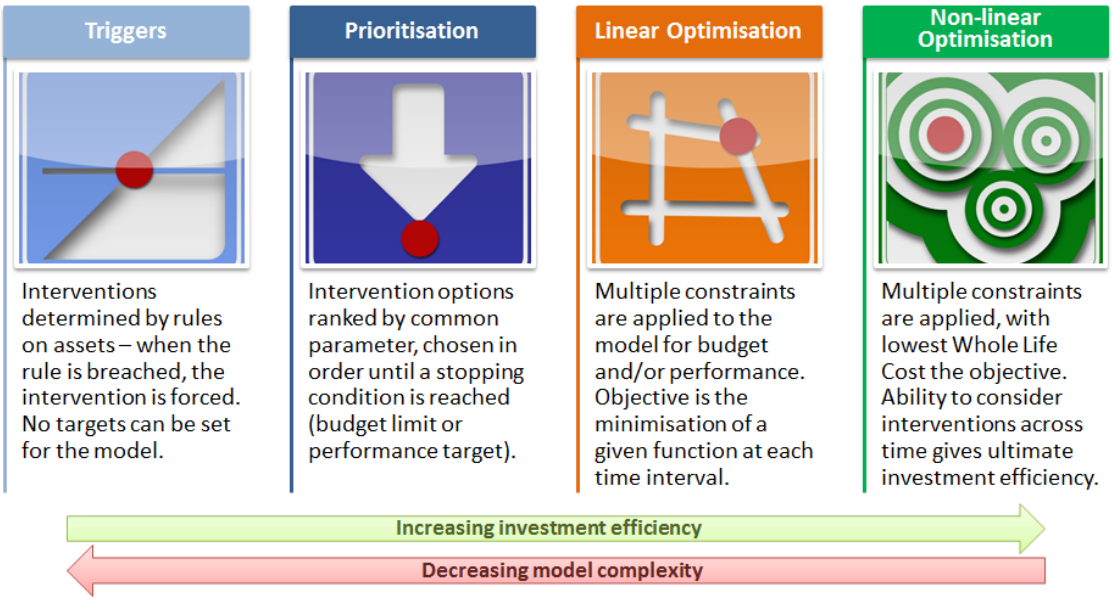


Figure 11 – Summary of Solver Methods

The concern with the current solver used is that certain materials (e.g. PVC & DI) are deteriorating relatively faster than others. A non-linear solver would most likely bring forward investments in these materials to resolve future problems today. Throughout a 25+time horizon this can lead to potential efficiencies of up to 10%, even in a single KPI modelled problem.

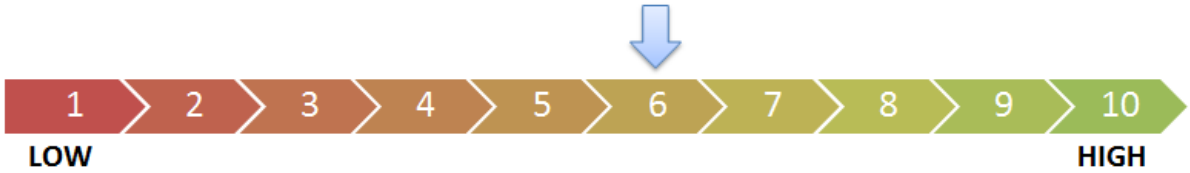
That said, the prioritisation logic includes a mechanism by which proximal high risk strings are connected together to create schemes. This is an excellent methodology that brings the outputs of the water infrastructure model closer to what actual schemes would be created operationally. As such, a relatively strong score of 6 has been given. Quantification of the impact of a non-linear solver would allay concerns and as SSW evolve the model to include other KPI such as interruptions and leakage then the solver method would need revisiting as the potential for investment efficiencies would increase significantly.

4.2 System

This section provides a review of the overall system designed and implemented for SSW water infrastructure model. A check of the system against the requirements set out at the start of the project is performed and then the system is scored in terms of:

1. Ease of use
2. Flexibility
3. Visualisation
4. Integration

4.2.1 Requirements



The development of this model came off the back of a critical review of the previous model in PR09. From this a number of key specific needs and requirements were documented. This section reviews how the current model holds up against these requirements and explores recommendations for the future as to how any gaps can be filled. Table 6 gives a high level summary.

25yr Forecast and 5yr Schemes

The model was required to have at least 25yrs of forecast and a minimum of 5yrs of schemes. The final modelled system empowers the user to set the number of years and schemes are produced for the full time horizon. In the model outputs viewed, 42 years were produced. This can all be achieved within reasonable solve timescales.

Link top down with bottom up

The model requirement was to ensure the deterioration model references specific pipes and then flags them for renewal. A concern of the previous model was that there was not enough granularity in the assets to be able to turn the top down investment scenarios into realistic and appropriate schemes at the ground level. By grouping like proximal pipes together via the concept of a string and allowing strings to be concatenated into schemes then this model criterion is met. Improvements in the cost model will help this further.

Easy to update/refresh

Failure and asset data is constantly changing and improving. SSW has a requirement to update the assets, deterioration and overall model on an annual basis. The aim is to turn the use of the model into a business as usual activity. The current system has gone some way towards enabling an annual model refresh. However, the configuration and population of the model requires expert knowledge of statistics and tools such as SQL which restricts this update to experts. Very little of the process is automated and therefore a refresh will be relatively time consuming.

Detailed Scenarios: Target End Rate

A requirement of the investment scenarios is to be able to set a “target rehab rate” at the end of the modelled time period and then let the solver decide the best way to transition to this end rate. To achieve this is a non-linear problem such that the solver has to understand the temporal implications of the pipe replacement it is chosen within any given year.

The current system allows the user to define the rehab length in every year but does not allow an “end target” only to be set. The only way to achieve this would be to consider applying a different solver method to the modelled system; the options include a non-linear GA or smart configuration of a linear optimiser (to allow investments today to be cognisant of the future).

Detailed Scenarios: Fixed Rates

A requirement of the investment scenarios is to be able to set the rehabilitation length in each year as a constraint. All the scenarios shown during the review were of this nature and the logic diagram supplied is designed around this approach to investment scenarios.

Detailed Scenarios: Limited Budget

A requirement of the investment scenarios is to be able to set a given budget (or a max/min) as a constraint within the simulation. Technically, this is not possible as costs are not included within the model. However, as there is only a single unit rate for proactive rehabilitation then a budget can be equated to a length and then this used as a constraint. As the cost model gets more complex this approach would not be possible. To achieve this, the SQL could be updated to output a cost and then the prioritisation solver (as per the logic diagram) can be amended to incorporate cost as well as rehabilitation length.

Detailed Scenarios: Max Failure Rates

A requirement of the investment scenarios is to be able to set serviceability targets in any given year and then optimise to find the minimum amount of rehab length required to achieve this. This functionality is not currently within the model. The SQL and prioritisation logic could be updated to incorporate this by adding code in which each year investment continue until the serviceability target has been met (it then moves onto the next year).

Execute numerous randomly seeded runs

A requirement of the model was to be able to execute numerous randomly seeded runs evaluating thousands of possible combinations to ascertain the most efficient strategy. For a given simulation, the current solver does not evaluate different combinations of investments. Instead it seeds the highest ranked string through prioritisation on burst rates and then works its way through the logic tree in a loop until each meets the required rehab length. Within the solver there is a smart scheme creation loop in which proximal strings are tagged together to create a scheme.

However, as the problem has been reduced to a prioritisation then there is no search space to explore, it simply works through the logic until all rehabilitation criteria is met. To achieve this requirement, a new solver approach would need to be considered.

Reflect Known Patterns

A requirement of the model was to reflect known patterns within the water infra network. To a certain extent the burst deterioration modelling carried out goes some way to achieving this. Further work is required around the other serviceability measures and any risk algorithm designed should also take into account historic numbers of bursts on the pipes within the strings.

Stochastic Variables

A requirement of the model was to incorporate stochastic variables such as weather trends and climate change. In the review carried out these variables are not considered. However, after quantification of the effects of weather on the network, the model should be able to be updated to evaluate the impact of weather and sensitivity of the model to these parameters.

Summary

In general, the model meets a fair percentage of its initial requirements. The biggest gap is that of flexibility of investment scenarios as the current model is restricted to prioritising based on a defined length of pipe rehabilitation. Some of the simulation requirements can be relatively simply added to the SQL solver logic, others would require consideration of more sophisticated solver methods.

As with all models, care should be taken to understand the trade-off between model complexities, model size and solve times. Attempting to simply bolt a non-linear GA optimisation onto the current system may result in a search space so large that solve times are unfeasibly long and it is never able to find the global optimal solution.

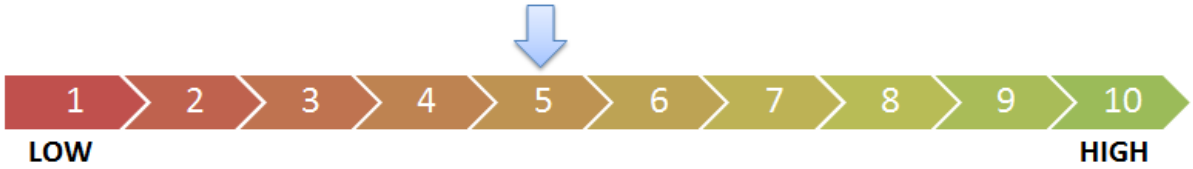
As the model evolves and complexity is added then it becomes increasingly difficult to maintain granularity in asset data. It will be important to prioritise what is most important to SSW with the model and then evolve the model in that direction.

In summary, the model is fit for purpose but can be improved in many different ways if SSW invests the time and effort to build on the system in place. This will add value to the organisation in many different ways, including more efficient investment and turning your model(s) into business as usual activities within operations.

Nr	Item	Score (1-10)	Comment
1	25yr forecast and 5yr schemes	10	The number of years can be easily changed and the system outputs schemes at a string level for all years of the model.
2	Link top down with bottom up	9	The strings used are a sound modelling concept to bring the top down approach closer to the bottom up. Furthermore, in the solver methodology each string is linked to its neighbours to allow bigger schemes to be created based on the connectivity of the network.
3	Easy to update/refresh	6	The system is tied into the GIS system (Strumap) so expert users should be able to refresh the data. However, system is reliant on SQL updates and specialised use of software which limits ease of update to experts
4a	Detailed Scenarios: Target End Rate	2	The solver method used considers one year at a time, so setting a target end rate and finding the most efficient journey to that is not possible within current model. Would require consideration of different solver methods.
4b	Detailed Scenarios: Fixed Rates	10	The user can set rehab lengths across all years of the simulation and the system has been proven to handle these scenarios with ease and in rapid times.
4c	Detailed Scenarios: Limited Budget	6	Costs are not explicitly accounted for within the model but as there is only a single unit rate, a length can be translated into budget constraints for the simulation. However, a more complex cost model would not allow this.
4d	Detailed Scenarios: Max Failure Rate	2	The system does not currently allow the user to put constraints on serviceability, only on rehab length within each year.
5	Execute numerous randomly seeded runs	4	Some functionality has been built in to change “scheme settings” but ultimately the solver method is a prioritisation on highest burst rates, therefore there is no search space to consider.
6	Reflect known patterns	7	The predictive analytics carried out on bursts is comprehensive. Further work required on other KPI and risk measures.
7	Stochastic Variables: Weather Trends	5	The model has the building blocks to allow weather trends to be included but to date this has not been applied. Further analytics would be required to quantify the impact and then it needs adding into the modelled system.

Table 6 – Model Requirements vs. Current Model

4.2.2 Ease of use



The ease of use of a system is particularly important if the vision of SSW is to incorporate it into business as usual, in which the system will be exposed to a wider audience across the business.

Following the review, it is clear that the developer and owner of the system (Gary Pearson) is able to quickly and easily ask questions of the model and respond to business requirements. A number of case examples were given during the onsite workshop.

Some of the features have been coded with a form to allow for easy input. However, the majority of the changes need to be made by opening up the SQL code and updating the settings. Whereas this is quick and simple for the model owner it does make understanding the model and making changes to it very much a job of the expert who configured it in the first place.

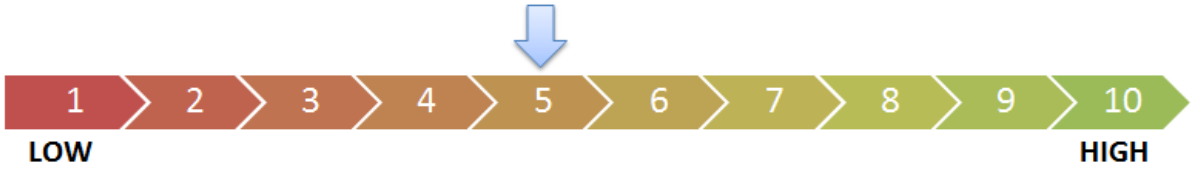
The system has a limited number of features so even with having to delve into the SQL the basics of running an investment scenario could be relatively quickly taught to someone who has a reasonable knowledge of databases/SQL.

The system links well with the STRUMAP GIS and the model owner made it look very easy to load up and view outputs from the investment scenarios into the GIS viewer. However, it is questionable whether this ease of use was more due to the familiarity of the system by the expert user as opposed to a purpose built and designed GIS interface.

Some standard outputs of the simulation is automatically generated which can be pasted into Excel. From here the ease of use for analysing the data depends on the Excel skills and capabilities of the user (which is generally quite high for most professional people). Asking for bespoke output data is more of a challenge and requires additional SQL queries to be designed.

In summary, the system is easy to use for expert users, of reasonable usability for technically capable people but very difficult to use for non-technical people. There is also a concern that if the model evolves to be more complex, having all configuration settings held within databases and SQL will make it increasingly more complex to use. As such, it scores 5 for ease of use.

4.2.3 Flexibility



A model should give the user enough flexibility to ask many questions of it and be able to edit or add features with relative ease. Throughout the review, the model owner talked through many cases where they have been able to quickly respond to questions raised to them from around the business. This gives confidence that the system, when used by an expert, is flexible enough to be amended to the requirement at hand.

However, as shown in Table 6 there were a number of initial requirements that have not yet been met and therefore the flexibility of the system to produce different kinds of investment simulations is limited.

As the model owner is able to generate his own SQL code then the system can be as flexible as the capability of the person writing the code. Some requirements are relatively simple but others would take a significant amount of time to add into the system, particularly for some of the more complex simulation requirements.

The system allows data to be output to Excel which in itself is a reasonably flexible tool for analysing the data. However, Excel does have a tendency to crash quite often with large data sets and with over 25,000 strings with multiple data associated with each, extensibility of analysis is a concern.

That said, in general the model owner has designed the system with as much flexibility in mind as possible given the timescales available. There has been a clear prioritisation of features to ensure SSW can answer their most pressing concerns through use of the model. As such, the model scores a reasonable 5 for flexibility.

4.2.4 Visualisation



Visualisation of data is proving to be an increasingly important aspect of any modelled system. Having strong visualisation makes the system easier to use as well as making communication of outputs more effective across a wide range of stakeholders.

The base data within the SSW model is held in a database and can be interrogated using SQL queries to return results in tabular format. However, this data would need to be exported into another package to interrogate further and visualise (e.g. graphs).

The model itself is not represented in any visual manner. Instead, there is a series of SQL code which represents the logic of the model. The setting of the model simulation constraints is also done within the model code.

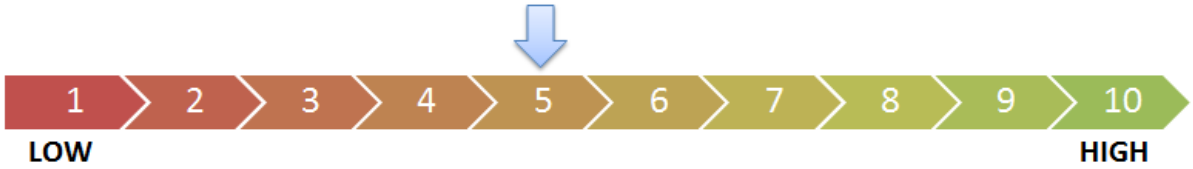
The model owner noted that it is possible to add forms on top of the SQL to make it easier to use and more visual. It was noted that has only been done for relatively few activities as up to this point in time there has been no other users of the model and it is faster for the model owner to interrogate and edit the raw code.

The outputs of the model simulations return in a standard tabular format that is primarily used to feed the IO tool. There is a transfer of data from the system into Excel (or other tool) if visualisation of the outputs needs to be carried out.

A key positive of the system is its GIS visualisation within STRUMAP. The results of the simulations can be loaded up into GIS and interrogated which provides a clear communication channel of model outputs for operations teams. There is concern though that a new GIS corporate system is being implemented in ESRI and this may end up leaving SSW with multiple GIS systems across the business (which has version control and auditing issues).

Having spoken with the model owner, given the maturity of the model, visualisation was not high on the priority list. The most effort was put towards integration with the GIS system and this was driven by a need to visualise the investment outputs for validation purposes. As such, a score of 4 is given.

4.2.5 Integration



A modelled system is more than sum of its parts. Data transfer across multiple parts of the system can be long manual exercises prone to error if strong integration does not exist.

The SSW model is all held within the STRUMAP/SQL system. It was unclear as to whether the source data it links to was the actual asset inventory or a “snapshot” of that data at a given point in time. As the asset data is 100% populated there is little pre-processing required of the data.

There is no integration between the SPSS analysis and the model. The model owner has to open up the SQL code and adjust it by editing the mathematical expressions and “where” code (to determine which assets the expressions apply to).

There is some limited integration between the burst model and the consequence tool, in such that a standard output file can be pasted into excel which is linked to the consequence control data.

The outputs of the simulations are processed into a standard format via the use of workbooks that can then be imported into the IO tool. It was unclear if the creation of these workbooks was a manual or automated process. If only a limited number of scenarios were to be input then a manual process is not an issue but if thousands are to be generated then the integration is essential.

The most impressive integration is with the GIS STRUMAP system which allows the user to interrogate the outputs in this environment. This part of the process looks relatively well streamlined and easy to use.

In summary, the model owner has built in integration where it was deemed a priority, for example the GIS and the input to the IO tool. As such, a reasonable score of 5 is given.

5. Conclusion and Recommendations

This section provides a conclusion and details the future recommendations for the model.

5.1 Conclusions

The overall score was 5.8 which represent a sound analytical and modelling effort by SSW. It is clear where the priorities within the model development have been, with all data, analytics and validation around bursts scoring very highly (8+). The SPSS analysis was excellent and a number of investment scenarios have been carried out utilising an intelligent scheme prioritisation method.

The key weaknesses lie in the lack of risk and the simple consequence model but this was a known issue when discussed with SSW. This can be remedied throughout AMP6 by developing an appropriate risk algorithm for inclusion within the model. It is also highly recommended that a robust sensitivity analysis is carried out to evaluate the level of certainty in the data and how important changes in the inputs are to the outputs.

In summary, the model is an excellent representation of bursts and gives SSW some sound investment planning scenarios for PR14. If the model is developed into the future then it can become an increasingly important, business as usual tool that is embedded around the organisation. There are a number of quick win improvements that SSW can carry out whereas others will be more complex and difficult.

Model	Field	Type	Item
Analytics (5.8)	Descriptive Analytics (6.5)	Data (6)	Assets (9)
			Performance (6)
			Interventions (5)
			Costs (4)
		Historic Analysis (7.5)	Serviceability Trends (7)
			High Level Analysis (8)
	Predictive Analytics (5.8)	Serviceability (5)	Bursts (8)
			Interruptions (3)
			Others (4)
		Risk (3)	
		Validation (7.6)	Burst Rates (9)
			Number of Bursts (9)
			Deterioration (8)
			Cross Correlation (6)
			Back Cast (6)
		Sensitivity (2)	
	Prescriptive Analytics (5.2)	Solver Method (6)	
		System (5)	Requirements (6)
			Ease of Use (5)
			Flexibility (5)
			Visualisation (4)
			Integration (5)

Table 7 – South Staffs Water Infra Model Score Summary

5.2 Recommendations

This section has a list of recommendations that SSW may wish to consider carrying out in the coming months and years to further improve their water infrastructure model. This is an exhaustive list and it is not assumed and/or expected that all will be carried out.

R1: Check Default Year Laid

There are some spuriously large lengths of pipe laid in single years which are likely to be default values. This is a relatively minor issue but it is recommended that this is reviewed and if possible the peaks smoothed out appropriately.

R2: Maintain data integrity during transition from STRUMAP to ESRI

During the implementation of new data systems, there is typically a period of time in which the integrity of the data is no longer maintained. It is recommended that processes are put in place to ensure this does not happen, but if it does then care should be taken in future analysis to account for any obvious data outliers.

R3: Interruptions Model Enhancement

It is recommended that more complex interruptions modelling be carried out. At the minimum the number of customers interrupted can be analysed by diameter. The more complex option would be to incorporate the outputs of hydraulic models to understand how many customers will be interrupted if a given pipe bursts. This can then be woven into the overall water infra model and used as part of investment scenarios.

R4: Discolouration Model Enhancement

As per interruptions, it is recommended that a more complex model is developed that makes full use of available data. There are a number of analytical techniques that can be employed.

R5: Supply and Demand Balance

Whereas this may be a step too far at the moment, in the future it would be possible to also incorporate supply and demand models into the system.

R5: Consider additional interventions

As the model becomes more complex and different KPI are added, then additional interventions should be considered. For example, the effect of flushing on the number of discolouration events can be quantified via a CUSUM analysis and this could potentially be added to the model as a new intervention.

The effect of pressure reduction on the number of bursts could also be quantified and if pressure is included as a parameter then the model has operational means of controlling bursts and leakage.

The effect of metering and water efficiency could be included to model demand reduction, which in turn would impact the overall supply and demand balance. Active leakage control could also be included if its cost and effect was quantified.

R6: Develop more complex cost model

It was noted by SSW that the two rates used are representative of the average intervention carried out. That said, it is highly recommended that a thorough review of the costs be carried out in the next evolution of the model and that a greater amount of granularity be applied.

R7: Include Costs explicitly within the model

Adding cost into the model as a common currency becomes increasingly important if the model evolves to include multiple serviceability measures and SSW wants to run scenarios that minimise the WLC of the network.

R8: Consider inclusion of discount rate within the Water Infra Model

It was noted that the discount rate is used in the IO tool. However, the packages of work supplied to the IO tool from the water infra model should be cognisant of the impact of future prices on the investment decisions. In the current model this is likely to have little impact but it is worth considering for future model development.

R9: Residual Value

Adding residual value to the model will ensure that the long term benefits of capital replacements are more accurately reflected.

R10: Add serviceability trends into future reports

It would be worthwhile showing the historic trends in serviceability in future reports as this frames the problem at hand upon which the model has been designed.

R11: Produce an High Level Design document

There are few people within water organisations that will understand the complexities of the water infrastructure model. To be able to effectively communicate to a wide range of stakeholders it is recommended that a high level design document be produced, which provides a simple summary of the model, how it works and its outputs.

R12: Further Investigate alternative age regression analysis

Some promising results were found with an alternative age regression analysis. Whereas the conclusion may be that this method is not sound, it is worthwhile investigating further.

R13: Use weighted regression

A weighted regression (by length) would have been more appropriate to capture all data points and ensure each point was weighted accurately in the line of best fit. This is likely to have minimal impact but worth exploring for validation purposes.

R14: Explore impact of pressure

Pressure was the one noticeable omission from the parameters explored.

R15: Consider Climate Change

Investigation into the impact of temperature and soil moisture levels is likely to show some correlation with bursts. This could be incorporated into future versions of the model. SSW did note that some analysis had been carried out, so it is recommended this be written up.

R16: Re-examine the DI age regression

There is an inverse relationship used for DI which persists through time. Analysing the model outputs this gives some spurious looking burst rates for old DI. It is worth re-examining the DI age regression and/or carrying out sensitivity analysis to understand its impact on model outputs.

R17: Beware CI pipes laid post 1990

Given the age regressions configured, any CI pipe laid post 1990 can have a negative burst rate. There were very few of these in the asset base but it is recommended that this is re-examined.

R18: Implement a risk algorithm

Section 3.2 provides details on how a risk algorithm could be included within the water infra model and how it would benefit the investment scenarios. This should be considered a high priority change to the model to ensure it is more risk focussed as opposed to driven by bursts.

R19: Include additional age checks for materials

It was found that some plastic pipes were stated to be laid prior to 1960, some as far back as 1905. Additional validation checks on pipe ages against the material should be included at the data stage.

R20: Calibrate to starting number

Different investment scenarios were carrying forward different starting numbers into the IO tool. To avoid this, a calibration process can be carried out to ensure the starting number in 2015 is always the same. As long as a single calibration factor is applied to all pipes, this will have no impact on proactive investment and it will make the reactive investment consistent across scenarios.

R21: Consider rationalisation of materials

There are a large number of materials in the model, some with as little as 0.1% of the network. As more complexity is added to the model (e.g. risk) then complexity may need to be removed elsewhere, this would be a good starting point.

R22: Examine high deterioration rate

The SSW deterioration rate predicted by the model is 1.7% per annum. This is higher than what SEAMS typically see in the industry of ~1%. SSW should be comfortable that this is an accurate reflection of the deterioration of their network so may wish to examine this further.

R23: Additional cross correlation

Some cross correlation analysis was shown but more could be carried out. If this has been done then it is recommended that it is included in future versions of the report.

R24: Carry out a Back Cast

As of the time of this final version, a first attempt at a back cast was carried out with promising results. A more detailed version of this analysis should be carried out where and when the data allows and it should be wrote up in SSW final reports.

R25: Carry out Sensitivity Analysis

To date, there has been limited sensitivity analysis carried out to understand the impact of changes in the input data to the outputs. Section 3.4 provides a potential approach using Monte Carlo.

R26: Explore different solver methods

There is some concern that given the rate at which PVC deteriorates that efficiencies could be found with a non-linear optimisation by bringing forward investment in these fast deteriorating assets. It is recommended that the impact of this and the efficiencies that can be gained are explored further. Furthermore, as the model becomes more complex and multi parameter investment scenarios are required, then different solver methods will need to be explored to ensure solutions can be found.

R27: Stick with the initial requirements

The initial requirements laid out by SSW for the water infra model are sound. A number of these have been achieved whereas others require additional development. It is recommended that continued effort is put into model development to continue to meet these requirements.

R28: Consider ease of use

The model is easy to update and use by an expert but less so for others. Implementing some forms to sit on top of the SQL or the use of a decision support tool could help improve usability.

R29: Enhance visualisation

The GIS element of the model is excellent. However, visualisation of the investment decisions made in tabular and chart form requires data transfers between different systems. Consider the use of dash boards or decision support tools to help improve visualisation.

R30: Consider Integration

Whereas this may be a low priority, a very mature and advanced model system will have significant integration between the data, analysis, model and visualisation of outputs. The ultimate in model will allow non-experts to click through buttons to refresh the model, run the model and to open up and interrogate the outputs.