Developing a Decision Support Model for the Rehabilitation of Non-critical Sewers

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INTRODUCTION

Since the 1980's the maintenance and asset management of the U.K. sewerage network has been based on a policy of selective rehabilitation of critical sewers, as defined in the Sewerage Rehabilitation Manual (WAA/WRc 1983,1986, 1994)[1]. These sewers represent about 20% of most drainage systems and in the last 15 years they have been brought up to an acceptable standard through the implementation of drainage area planning procedures. Less attention has been given to the remaining 80% of non-critical sewers which hitherto have only received unplanned reactive maintenance. Experience has shown that many problems such as blockage, odour and collapse continue to occur on the non-critical part of the system which is made up of smaller diameter pipes, often laid at slack gradients, where serviceability problems of siltation, protruding connections, infiltration, fat deposition, encrustation and root infiltration have a disproportionate effect on their performance. Continuing failures on an ageing network, together with customer and regulator pressure, have increased the need for water companies to become more pro-active in the maintenance of non-critical sewers.

It is not cost effective for the water industry to CCTV inspect all its sewers, and so a simple method of targeting pre-emptive maintenance and rehabilitation strategies is required[2]. This paper describes a decision support model which has been developed to interrogate historical sewer event data in order to rank pipes in susceptible areas into priority order for attention.

DATA AVAILABILITY AND METHODS OF ANALYSIS

A data availability survey of 9 water companies and several local authority drainage departments revealed that for retrospective analysis the majority of historic event data only existed as a paper record. In most cases this was in the form of a house address with no information to automatically link a past event such as a blockage to the relevant pipe in the ground. It was concluded that the only data fields consistently available were pipe material, sewer type, pipe size and event history. Although some information such as soil type or pipe gradient could be abstracted from elsewhere or inferred from other information it was not recorded in standard databases. Little systematically recorded information was held on pipe age, adjacent environmental factors such as tree growth, traffic loading or on costs of pipe repair.

A method of analysis needed to be devised which could overcome the lack of connectivity between asset and event databases and could handle missing data information without recourse to substituting extensive quantities of default values which would distort the results and mislead their subsequent interpretation. Asset and event data was provided by 5 water companies with the historical performance of the sewers in 4 catchment areas (divided into 12 separate drainage areas) analysed in detail. Data from over 2000 km of sewer pipes were considered in developing the procedures described below. A decision was made to apply any analysis to all the sewer information available rather than restrict the examination by pre-selecting only non-critical sewers.

A range of statistical approaches to handling and manipulating the data were considered including the use of neural networks, fuzzy logic, survival analysis, logistic regression and Bayesian statistics. Most of these methods were rejected because of their requirements for extensive and comprehensive data. To overcome these problems a two stage hierarchical model was developed which was robust enough to operate with current levels of data availability[3].

OVERVIEW OF THE DECISION SUPPORT MODEL

The methodology proposed is summarised in the flow diagram shown in Figure 1. The approach is flexible allowing each water company to set its priorities and threshold levels of service in response to its own budgetary and regulatory pressures. Furthermore, the analysis techniques proposed can be easily refined and adapted as more relevant information and data becomes available in the future.

The first stage has been designed for use with drainage data in its current limited form and is based on the analysis of data contained in a series of grid squares represented in a GIS programme. This is intended to provide an immediate coarse screening tool for the water industry. The second stage performs a detailed Bayesian statistical analysis of each pipe length within those grid squares considered most at risk from future sewer failure. At present this requires considerable data manipulation to form the necessary asset to event linkage, by matching the address of each recorded complaint with the separately recorded asset information. This stage demonstrates the level of analysis which can be accomplished if good data collection and linkage is achieved in the future. The output can be used to identify those pipe characteristics which are diagnostic of sewer failures from which failure probabilities associated with different combinations of these characteristics on individual pipe lengths can be calculated. The analysis has shown that those pipes which display a greater number of these diagnostic factors on any given length have a higher likelihood of failure in the future. This information can be used to help target specific pipe lengths in any pro-active maintenance strategy and can be applied to all sewers in the drainage network.

The proposed procedures can be followed with limited data availability, which typically would include event history, pipe depth, pipe size, pipe material and pipe type. In addition information on pipe length and pipe gradient can often be inferred from the basic data and when this is included the analysis can be refined. Little systematically recorded information was found on pipe age, pipe bedding and soil type or surface loading and so these factors could not be addressed in the analysis.

STAGE A: GIS and RISK ASSESSMENT: CONCEPT OF CRITICAL GRID SQUARES

Once all asset and event data has been collected, screened and entered into a database, a GIS programme (MapInfo) can be used to view the data in a series of 500m x 500m grid squares which are superimposed over the catchment. This allows the total number of past events recorded in a grid square to be related to the summary statistics of all pipe characteristics in the square, thus avoiding the need to make specific asset to event linkages for each pipe.

A simple algorithm is then used to rank each grid square according to their likelihood of future sewer failure, based on their past event history. Several algorithms were investigated for this purpose using data from a number of catchments. These included consideration of repeat events within a square, the number of events in adjacent squares, and physical pipe characteristics. The algorithms were tested by comparing the predicted rank order of failed squares with the observed rank order based on the number of actual events in the last year of the data record, using the non-parametric Spearman's rank correlation. The algorithm based on the number of past events in each square was found to be the best predictor of future failures, consistently giving a rank correlation in excess of 0.8.

A second algorithm is used to allocate a consequence factor to each grid square. This has been developed to allow for the impact of sewer failure on global issues which affect the whole community such as potential traffic disruption, environmental damage and pollution of water courses as well as issues affecting individual customers such as flooding, blockage and odour nuisance. The algorithm can be modified by adding further factors to allow, for example, for road category and weightings to reflect individual water company priorities.

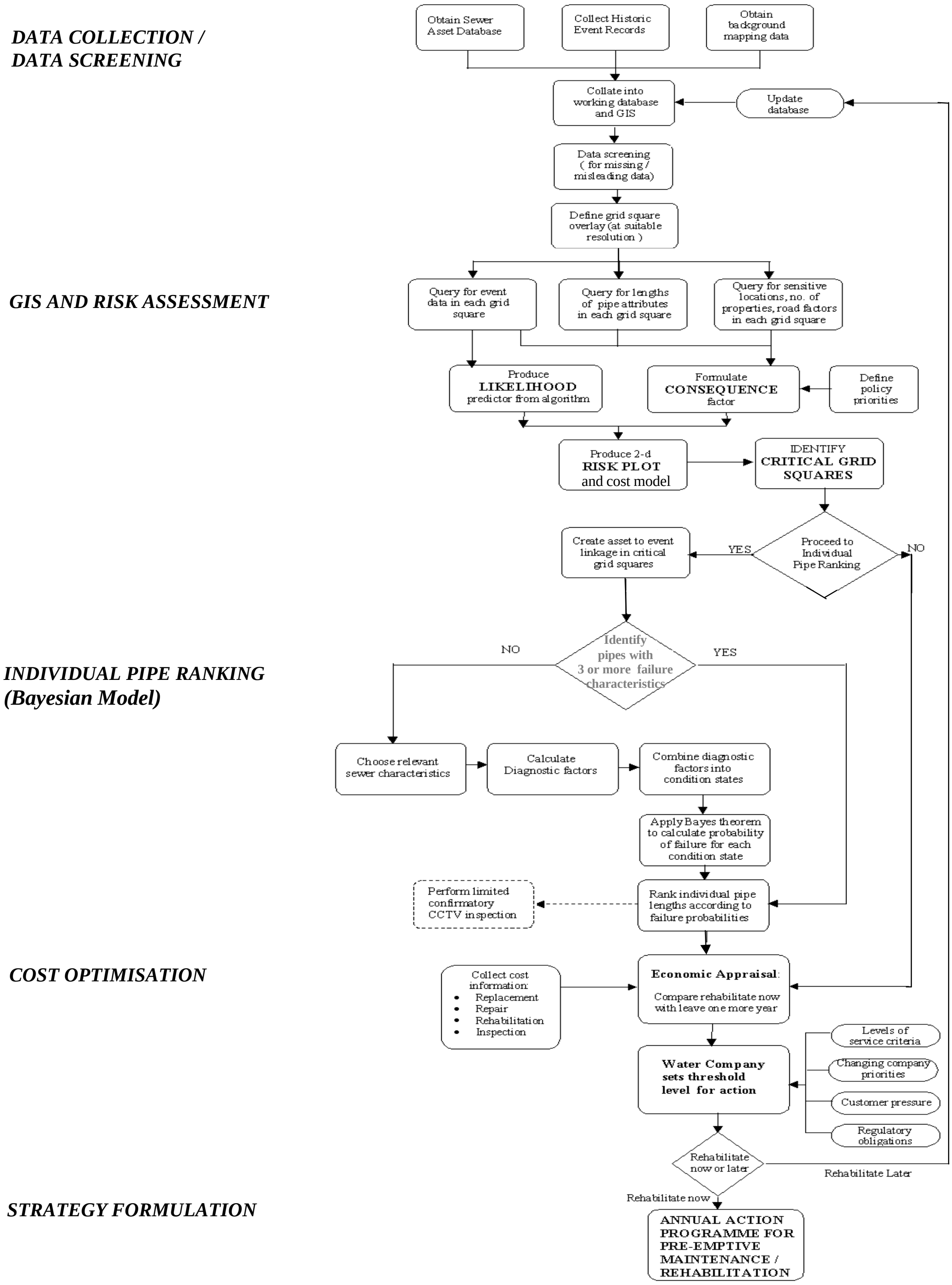

Figure 1: Flow chart for a decision support model for non-critical sewer maintenance

The likelihood of future events occurring in a grid square is connected with the consequence factor for that square graphically in a 2 – dimensional risk plot, as shown in Figure 2. Those squares appearing in the top right quadrant are those which should receive priority attention.

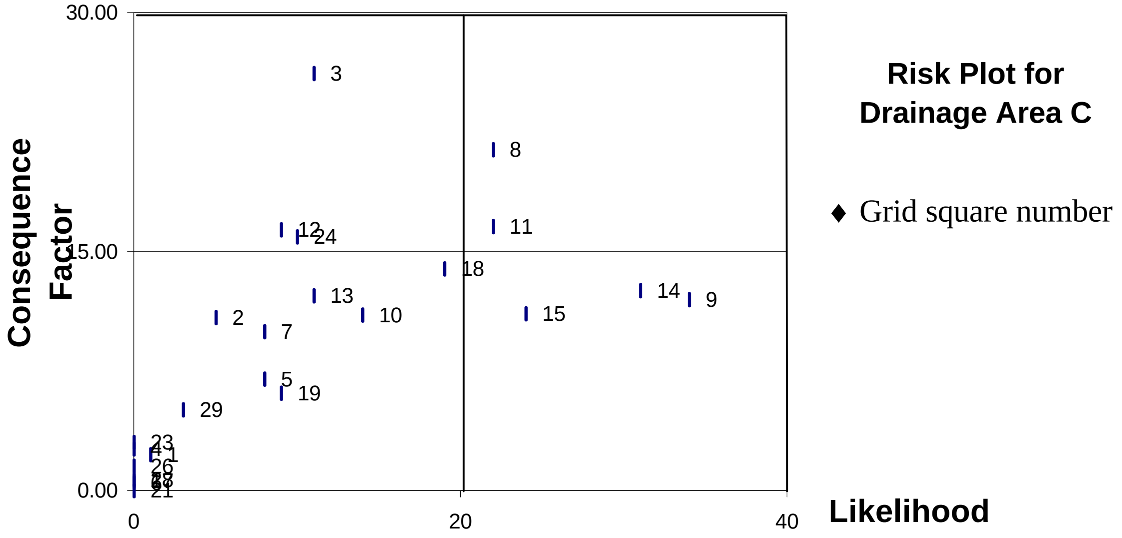

Figure 2: A 2 –dimensional risk plot applying likelihood and consequence algorithms to drainage area C

A simple cost model is applied to measure the relative cost to perform maintenance within a square. Cost data is not stored by water companies for individual events and so default costs of rehabilitation options based on diameter and depth of pipe, in good and bad ground conditions have been used. This cost information highlights those grid squares which would be cheapest to rehabilitate so that the most cost-effective actions can be identified and prioritised accordingly, and can be displayed in a radar plot as in Figure 3.

The procedure moves from the previous practice of identifying single critical sewers to the consideration of critical grid squares in which both the critical and non-critical sewers are considered for rehabilitation. The philosophy underpinning this approach accepts that the best practical unit of management within a drainage network is unlikely to be a single pipe because of the nature of maintenance operations. This provides an initial coarse screening tool which can be used to systematically identify hot-spot areas of sewer failure.

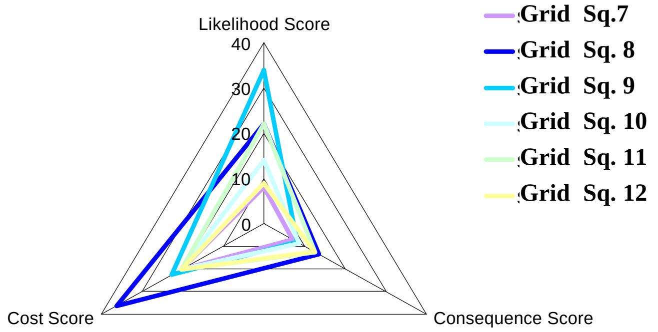

Figure 3: Radar plot for 6 grid squares combining likelihood, consequence and cost factors

STAGE B: INDIVIDUAL PIPE LENGTH ANALYSIS USING A BAYESIAN STATISTICAL MODEL

A more detailed analysis can be applied to individual pipe lengths in those grid squares which have been identified as at risk [4,5]. This applies a Bayesian statistical model by adjusting the catchment wide average probability of failure based on the characteristics of each pipe[6]. A diagnostic ratio is used to determine whether pipes with certain characteristics have a higher than average incidence of past failure. Once the significant pipe characteristics have been identified these are grouped together in a series of combinations (condition states) and the overall probability of failure computed by applying Bayes theorem. The results provide a set of condition states ranked in order of failure probability.

In catchments with brick sewers the analysis showed that these had a high likelihood of failure and should receive priority attention, confirming their status as Critical A sewers under the existing SRM definition. Other diagnostic pipe characteristics which were commonly found to be associated with higher than average failure rates were long pipe lengths (50 –200m), small diameters (< 225 mm), shallow depths (0-2m), moderate to slack gradients (< 0.01) and foul sewers. Pipes with these characteristics would often be classified as non-critical sewers under current SRM practice. Similarities observed from the drainage areas analysed showed that when more of the diagnostic factors are present in a single pipe length, a higher probability of future failure can be anticipated allowing non-critical sewers to be screened on this basis to help prioritise any given pipe into a planned programme of maintenance. The analysis procedure could be applied by a water company to its own data sets should it wish to produce its own catchment specific rankings.

CONCLUSIONS AND RECOMMENDATIONS

The work has led to some insights into the nature of sewer failure on several drainage systems. Specifically, a high percentage of past failures occur on Section 24 sewers which often are not recorded in existing databases and remain undescribed in the reporting procedures completed by maintenance operators when performing a repair.

On the basis of the analysis of data from the 4 catchments studied in detail pipes which were most prone to failure had the following characteristics: small diameter, shallow, foul sewers. Pipes with these characteristics are typically found on the non-critical part of a drainage network. Therefore a more holistic approach to the management of sewerage assets should be taken with pre-emptive maintenance and rehabilitation being extended to cover all sewers.

Failures are most often reported simply as blockages and because they occur frequently on the non-critical part of the system they are usually cleared by reactive maintenance such as rodding and jetting. However the study has shown there to be a high incidence of repeat events once an initial problem has occurred, suggesting current maintenance practices are tackling symptoms of the problem and not the cause. This is likely to be some physical change in the fabric and integrity of the pipe such as root infestation, misaligned joints, protruding connections or even partial collapse. The implications of this are twofold: continuing expenditure is being incurred in returning to locations which experience frequent failure, which in turn impacts on customer perception of the water industry and its ability to manage its assets. A change in emphasis is therefore needed which heeds the cause of blockage events in addition to simply clearing them. A programme to pro-actively tackle these issues in areas with a high past frequency of events is likely to reduce future incidents significantly.

A detailed methodology, in the form of a decision support tool for identifying areas where proactive maintenance and rehabilitation of non-critical sewers is likely to be effective, has been proposed on the basis of an analysis of past performance records[7]. The procedures have been successfully applied to data from 12 drainage areas within the 4 catchments studied. The work is likely to be significant as the water industry is needing to respond to customer pressure and increasing demands from the regulator OFWAT for strategies which are seen to manage the whole drainage network.

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DISCUSSION

Question Richard Allitt Richard Allitt Associtates

Did you look at pitch fibre pipes?
Did you do any analysis on repeat blockages especially those occurring quickly (within 2 days) ? These indicate blockage may not have been properly cleared.

Answer

We received a lot of anecdotal information from drainage area managers that pitch fibre pipes caused many problems. However the data sets we analysed in detail did not contain records of pitch fibre pipes, either because material was not specified at all (in some cases) or there were no such pipes recorded in a particular catchment where the records only indicated concrete , clay or brick sewers. Our analysis showed that brick pipes were strongly diagnostic of failure events, and in some cases clay pipes also produced a significant diagnostic result. Concrete pipes were found not to be associated with failures.

With respect to repeat blockages occurring within 2 days , we generally found that the water company databases recorded these as a single event if a revisit had to be made to rectify only a partially cleared pipe. Repeat events we studied were much greater than 2 days apart. However once a repeat event had occurred, it was often found to recur with increasing frequency with time span of successive visits being reduced from several months down to a matter of a few weeks.

Question Martin Osborne Reid Crowther

Water Plc's are looking at longer lengths between manholes on new systems. Can you comment on this and any additional risks.

Answer

We looked at three pipe length categories and the longer length (between 50-200m) was most clearly associated with past failures. We can speculate on the reason for this, such as the difficulty of rodding and clearing blockages as the distance between manholes increases. Also longer lengths may give rise to the probability of finding an increased number of misaligned or displaced pipe joints. The reason we studied pipe length was to use this as a crude indicator of the number of lateral connections. Thus longer lengths of pipe may suffer from a greater number of protruding or poorly made connections, which may act as sites to accumulate and cause blockage.