Risk assessment of Sewer Systems

Analyse des risques dans les réseaux d'assainissement

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RESUME

Alors que dans de nombreuses industries la prise de décisions est fondée sur une analyse des risques, cette pratique reste exceptionnelle en assainissement. Dans ce domaine, il est courant de prendre des décisions intuitives en impliquant seulement quelques employés clés possédant une connaissance des systèmes. Cette étude montre que l'analyse des risques ainsi que l'analyse coût-bénéfice apportent une base solide pour la prise de décisions dans le secteur de l'assainissement. Cela est principalement du au fait que ces méthodes permettent de comparer des aspects différents du réseau d'assainissement. Copenhagen Energy, la société responsable des égouts de Copenhague, effectue actuellement une analyse des risques dans les réseaux d'assainissment.

ABSTRACT

While it is common practice to make decisions on the basis of risk assessment in many technical industries, it remains exceptional in the urban drainage industry. Here it has been established practice to make decisions on an ordinary commonsense basis, with key personnel with systems knowledge involved. This study shows that the inclusion of risk assessment and cost benefit analyses provides a solid basis for decision-making in the sewer sector. This is primarily because these methods allow for the various considerations of a drainage system to be viewed comparatively. Copenhagen Energy, who is responsible for Copenhagen's sewer system, is currently carrying out a wider risk assessment of the sewer system.

KEYWORDS:

Asset management, cost-benefit analysis, modelling, risk assessment, sewage systems.

1 INTRODUCTION

Risk assessment is a tool for analysing the risk of system failure in a rational way, which allows for the prioritisation of resources in reducing said risks consciously and pro-actively. While risk assessment has been commonly used in a wide variety of technical industries in recent years, it has yet to find its way into the sewage sector, despite these methods appearing well suited to operational and planning type goals.

The conceptual principles underlying risk assessment are intuitively employed every time a decision is made in the sewer sector. This occurs via subjective evaluations, taking the form of ”gut feelings” or ”rules of thumb”. It is, however, exceptional for decisions to be made on a systematic and documented basis where various considerations are weighed up in relation to each other. A drainage system is based on a given financial budget, within which all the different requirements have to be met. It is, therefore, of decisive importance that the available resources are used in the most efficient way.

But how are decisions to be made when it comes to allocating funds for the various considerations that the leadership of an urban drainage system are responsible for ? Considerations that include, for example, employee safety, basement flooding, compliance with bathing water regulations, the public image of the sewer system, customer service, reliability, protection of recipients in accordance with the Water Frame Directive, disease prevention, maintenance of sewer system, countering the greenhouse effect and so on. This is when the pressing need for a risk assessment combined with a cost benefit analysis comes into the picture.

2 THE STUDY AREA

This study is a pilot project, and the first of its kind, in the use of risk assessment in the sewer management in Denmark and, as far as we know, in the EU. The pilot project has been carried out in cooperation with Copenhagen Energy, which runs Copenhagen Council’s sewer system. The sewer system covers a 9000 hectares large area of Copenhagen. The sewer system serves around 500,000 inhabitants. The total length of all the sewer pipes in the system is approximately 1200 kilometres with around 35,000 service pipes, 20,000 street drains, more than 100 technical stations, and 120 outlets to recipients. There are furthermore connected a large amount of highly sensitive users, including nursing homes, public institutions, hospitals and companies.

It is not the intention to carry out a full, detailed risk assessment for the whole area as that would require a very high level of resources. Rather, a ***screening*** of the system is undertaken, where selected localities are picked out for closer analysis. Screening is a dynamic process, which is undertaken on an ongoing basis. To carry out the most proficient screening, experts with particular knowledge of the sewer system are called in to a series of meetings, where experiences and general operational data are presented in a structured way. Specialised investigative tools developed for aiding risk assessment, such as HAZOP, are employed. This is of key importance as it allows for employees from all levels to be included in the process.

3 METHODS AND APPROACHES

Figure 1 shows the procedural outline followed in risk assessment. With the assistance of the experts’ knowledge, the most important localities are first selected for closer analysis, which set the parameters for the project. The next stage involves the presentation of the data necessary for forming an initial rough risk assessment, which allows for the screening of the most significant risks for the particular installation. From this is produced a series of unacceptable critical relations and a further evaluation of risk-reducing measures, which can prevent the unacceptable risks. There can also arise a need to carry out a more detailed risk assessment for certain installations, before suggestions can be made regarding risk-reducing measures.

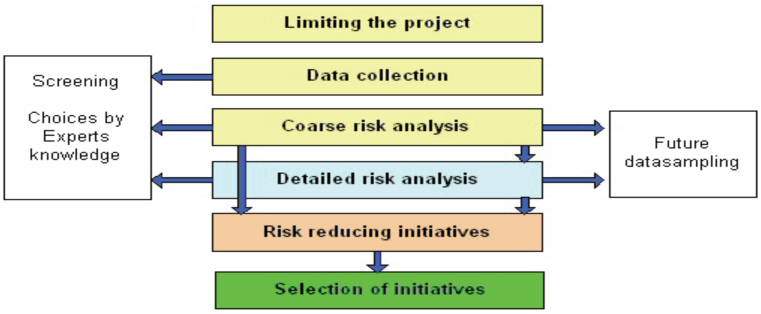

Figure 1 : Procedural outline followed in risk assessment

The process is dynamic and involves the continual introduction of new knowledge to the presentation of the data in the risk assessment. This can have the consequence of either highlighting new localities as risk areas, or of excluding others, which do not, upon closer examination, represent after all an unacceptable risk. Localities should be chosen on the probability of a problem occurring and the extent of the outcomes related to that. The chosen localities, which have an unacceptably high level of risk, will then be analysed further with the aim of identifying risk-reducing measures. These measures will aim to reduce the level of risk to an acceptable level at the cheapest possible cost.

4 THE COST-BENEFIT-RISK CONCEPTS

4.1 Defining risk

Mathematically, risk is defined as its probability multiplied by the consequences of any given undesired event. The primary goal of risk assessment is to identify and quantify undesired events which may occur and the losses or outcomes that they lead to. A risk assessment is made up of the five following levels:

1. What can go wrong? 2. How probable is it and what are the likely consequences? 3. How can the situation be improved? 4. What is the economic cost and what are the economic and benefits of the improvement? 5. Which risk-reducing measures should be set in motion?

4.2 HAZOP

HAZOP stands for HAZard and OPerability in association and is made up of several steps, as shown in Figure 2. The HAZOP methodology is a qualitative risk assessment, whose goal is to disclose types of error and their consequences, which can occur in an existing system as well as changes to that system. The method is based on brainstorming in meetings, and is established as a powerful and well-structured analytic tool. See Kletz (1992) or Henley and Kumamoto (1992) for further details.

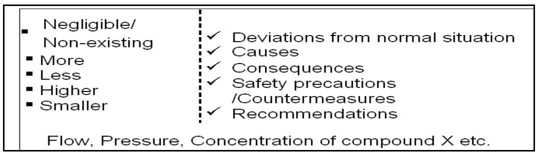

Figure 2 : HAZOP method.

4.3 Defining risk matrixes

As there can be found many different types of risk and consequences, it is necessary to define 2 matrices: a frequency and a consequence matrix.

4.3.1 Frequency matrix

One example of a frequency matrix is shown in Figure 3. The matrix expresses how often any given undesired event occurs. The frequency is partly given by a qualitative scale going from "very frequently" to "extremely rare", and partly by a quantitative scale, which roughly describes the frequency and repetition periods for an event as a numeric value. It is important that both the qualitative scale and the quantitative scale are defined in a way that attains a broad agreement around the concepts. It should be noted that the quantitative scale is logarithmic.

Nr.	Frequency category	Yearly frequency	Range
6	Very often	> 10	Daily – month
5	Often	1 – 10	Month – year
4	Probable	0.1 –1	1 – 10 years
3	Moderate	0.01 – 0.1	10 - 100 years
2	Rare	0.001 – 0.01	100 – 1000 years
1	Very rare	0.0001 – 0.001	1000 – 10000 years
0	Ekstremely rare	< 0.0001	> 10000 years

Figure 3 : Frequency matrix.

4.3.2 Consequence matrix

Figure 4 shows an example of a consequence matrix. In order to create a common scale for different types of consequences, it is necessary to group these in a matrix. Just as with the frequency matrix, the consequence matrix is expressed both qualitatively and quantitatively. The qualitative scale runs in gradated steps from "nothing/negligible" to "very serious". The quantitative scale is an economic scale, which can be seen at the bottom of the matrix. All consequences can be quantified economically, that is the definition of risk as an anticipated loss. This applies also to what can be termed "softer values", such as, for example, nature, working conditions and so on. As with the frequency matrix, this is also assembled as a logarithmic scale. It is important to underline that the vast majority of figures in the consequence matrix are not arbitrarily set, but derive from previous experience and the general practice of risk assessment.

		Non/ Negligible	Marginal	Considerable	Serious	Very serious
Type of consequence	Id	0	1	2	3	4
Employees	P					
The public	N					
Environmental	E					
Equipment/ material	M					
DKK		< 10.000	< 100.000	< 1.000.000	< 10.000.000	> 100.000.000

Figure 4 : Example of a consequence matrix

4.3.3 *Risk matrix*

Figure 5 shows an example of a risk matrix, in which the risk level varies between whole digit values from 0 to 10. The risk matrix consists of a vertical measure of the frequency groups and an horizontal measure of the consequence groups. As we are using a double logarithmic matrix, the level of risk on all straight lines is identical with an inclination of -1. This means that an undesired event that has a frequency of "very often" and a consequence of "marginal" has the same risk level as an event with the frequency of "probable" and the consequence of "very serious", (which is registered as level 7). It should be noted that, because the risk matrix is double logarithmic, the frequency number and the consequence number should be added rather than multiplied, as the definition of risk actually is measured as (risk = probability*consequence).

Ranking		Consequence				
		Nonexisting/ negligible	Marginal	Considerable	Serious	Very serious
Frequency		0	1	2	3	4
Very often	6	6	7	8	9	10
Often	5	5	6	7	8	9
Moderate	4	4	5		7	8
Probable	3	3	4	5	6	7
Rare	2	2	3	4	5	6
Very rare	1	1	2	3	4	5
Extremely rare	0	0	1	2	3	4

Figure 5 : Example of a risk matrix

Every undesired event, such as a broken pipe for example, (represented by the large dot in the risk matrix), has a series of unintended effects with specific frequencies and consequences. These could entail overflow to recipients, basement flooding, risk of infection, material damage and so on. The specific risks of the effects resulting from the event are represented in the figure by the smaller dots, which are summarised in Formula 1, below. This formula gives the combined risk as it is represented by the large dot :

$$R_{samlet} = \frac{\ln(\sum \exp(R_i \cdot 2{,}3026))}{2{,}3026} \qquad \text{(Formula 1)}$$

, where R_i stands for the single partial risk dot and R_{samlet} is the combined risk level for the undesired event.

Utilising the risk matrix, the various events can be systematically ranked on a comparative basis, that is to say the risk of failure of system components such as pump stations, broken pipes, reservoirs and so on, can be directly compared with each other. Risk assessment thus opens up the possibility for investing in those localities where risk can be maximally reduced for any given investment.

4.3.4 *ALARP*

ALARP is a band in the risk matrix, which expresses the acceptable risk level for the individual drainage system. ALARP stands for As Low As Reasonably Practicable. Its position in the matrix is governed by the urban drainage system's economic resources. If this band is, for example, pushed towards 5 or 6, events whose risk is higher should be brought down. This is done via risk-reducing measures.

4.4 Bayesian Networks

The described calculation of the risk is based on a rather rough assessment of the probability and consequence of specific incidents. Actual modeling, which is able to disclose complicated causal relations in the sewer system, has also been applied – based on Bayesian networks see Jensen (2001), Friis-Hansen (2004) This is performed by means of a graphic model – Hugin , (www.hugin.com) – which is built up by means of nodes, describing an uncertain quantity by a set of possible conditions, (stochastic modeling). These nodes are connected internally and the connections describe the interdependence between the nodes. In order to calculate the risk, it is necessary to describe a probability distribution for all the nodes, and these are quantified based on qualified technical knowledge of the sewer system design, current condition and function.

When the network has been fully modeled and the incoming probability distribution has been specified, the probability distribution for the total consequences can be calculated. This is in itself interesting, as it is possible – on the basis of this distribution – to calculate the risk. However, this is far from the only possibility. The Bayesian network can also be applied for identification of inferences, when part of the network has to be in a specific mode, e.g. in the case of modifications or maintenance.

By extending the network to include cost and decision nodes, the most cost-effective decisions can easily be identified. A decision node could for example describe the degree of maintenance or modification that could be performed in a given pipeline or in a given area. A cost node would describe the costs involved based on the assessment of the potential reduction of frequency and/or consequence.

4.5 Cost benefit analysis

For high risk elements, technical measures are established to reduce the risk, and the effect of the risk-reducing is assessed by means of a new risk calculation including the effect of the risk-reducing measures. The risk reduction is called dR and is expressed as the annual saving obtained through the reduction of the risk level. Also, the finances involved, (capital costs and operating costs), for implementation of the risk reducing measures is set up, and is converted into an annual cost called dC, applying the cost benefit approach. , see e.g. Friis-Hansen (2002).The ratio between dC/dR expresses whether it is profitable to reduce the risk for the elements in question. If the ratio dC/dR is less than 1, the risk-reducing measure will be a good investment and vice versa.

5 RESULTS AND CONCLUSION

5.1 Preliminary risk screening

The initial risk screening of the sewer system and its components allowed for the selection of 23 localities with a possible high risk level, some of them shown in Figure 6. The selected localities with a possible unacceptably high level of risk have to be analysed more closely in order to identify the precise risk level and if this level is to high, possible risk-reducing measures, which can bring down the risk level to an acceptable level.

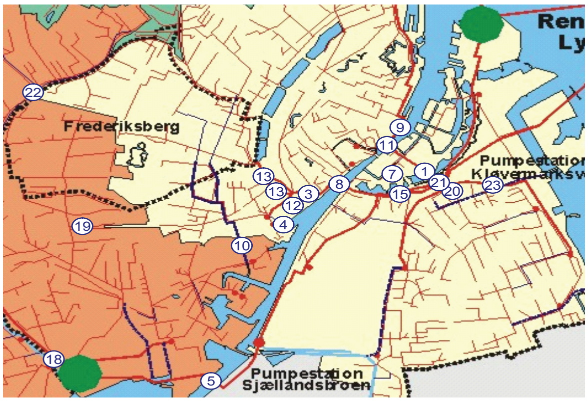

Figure 6 : Mapping of selected possible high risk localities.

5.2 Pipe connection to the Klovermarks pumping station

As an illustration of the use of risk assessment by Copenhagen's Energy, we will look more closely at point 1 on the map (figure 6).

5.2.1 Details about the pipe connection

The pipe connection to the Klovermarks pump station was established in 1903. The pipe drains a large sewered area to Klovermark's pumping station, which then pumps the water on to the Treatment Plant, Lynetten. Apart from the 903 metres of combined stretches of pipe, there is a length of approx. 270 metres lying under the water. A break in this pipe will cause extensive overflow into the harbour area in the space of a very short time. Dry weather flow varies between 200 l/s and 600 l/s throughout the day.

5.2.2 Rough Risk Analysis

A broken pipe has been analysed using a rough form of risk assessment, utilising the frequency, consequence and risk matrices that have been developed. Significant consequences are introduced into the assessment as follows: Material damage, (CE's own material); environmental impact; bathing water quality and sickness/injury amongst both CE's employees and the employees of the subcontractors involved in the clean-up. The combined risk level for this broken pipe is calculated to 6.6, which corresponds to an economic loss of 4.2 million DKK per year. The level of risk is above the ALARP, which CE has defined. Risk-reducing measures should, therefore, be set in motion to bring down the risk level to an acceptable level for CE.

5.2.3 Risk reducing initiatives

In order to carry out a more detailed assessment of risk, the pipe was divided into five separate stretches. This revealed that both events designated as "highly reduced flow" and "reduced flow" led to a high risk categorisation, events which were caused either by a break or blockage of the pipes. The frequencies of these events were established as between 3 and 4, which corresponded to occurring between once every 10 to 100 years and 100 to 1000 years. Realistic measures to reduce the frequency risk were, however, not identified. The reduction of the frequency risk would only be made possible by the replacement or supplementation of the existing pipes. A reduction of the risk level, however, could occur by reducing the consequences of an event. A detailed risk assessment and cost-benefit analysis showed that by far the most effective reduction of risk would be achieved by a reinforcement of the dry weather flow in comparison to reinforcing the full capacity in the case of rain. Risk reduction can take place in two ways, either through the storage of water or through relocating it while the repair work is carried out. It was shown that the storage of water was a totally unrealistic strategy as the dry weather flow alone is the magnitude of 400 l/s, which amounts to around 35,000 cubic metres per day. The repair time is estimated at 3-4 weeks. Therefore the relocation of the water in the system is the preferred option while repairs take place. In this way, 7 proposals could be devised for risk-reducing measures. These can be divided into 3 categories: installation type improvements; transportable improvements; and a rapid response strategy. Installation type improvements apply to the permanent situating of pipes, so securing a separate pathway for the dry weather flow from the pump station. A transportable improvement has to be ready at short notice to pump the water around the point of breakage until the break is repaired. The rapid response strategy involves pumping water using existing or rented equipment. These 7 different initiatives were then exposed to a cost-benefit analysis and the results can be seen in Figure 7. Here it is shown that alternative B1 has the lowest dC/dR ratio, and is thereby the most advantageous.

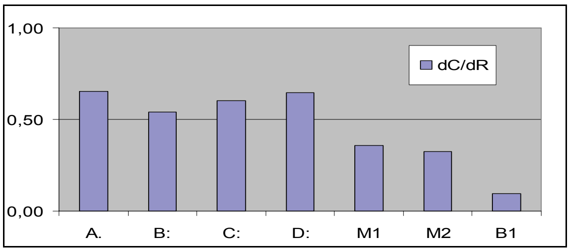

Figure 7 : dC/dR ratios for 7 different risk reducing initiatives

5.3 Conclusion

This study has shown that the cost-benefit risk concept has a lot to offer as a decision-making tool, arming management within the urban drainage sector with the ability to take clear, rational, well-considered decisions. Until now most decisions have been taken on the basis of “gut feelings”, involving only few key personnel, as the economic impact of, for example, personal injury, damage to material, environmental harm and so on were taken in to consideration later in the process. Copenhagen’s Energy currently utilises the Asset Management tool in order to establish future investment requirements and priorities for the Copenhagen municipality. Risk assessment constitutes a vital aid to Asset Management and could, therefore significantly contribute to the optimization of the future investment profile for Copenhagen Energy.

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