IMPLICATIONS OF FORENSIC INVESTIGATIONS TO PREVENT WATER SYSTEM FAILURES IN HEALTH CARE CENTERS

(Literature Review)

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Outline of Review of Literature

Introduction:

Water supply infrastructure and the network designed for the water supply holds a key importance for its users. From the past, a number of methodologies are in practice to evaluate the performance of water networks. These methodologies are more inclined towards the prevention of harmful error prone processes, rather than focusing on the corrective actions against the causes of system failures. Block (2017) explained forensic based investigation as a tool which determines the root causes of the system failure which cannot be observed with the thorough analysis. The forensic methods are being used to evaluate the failures after the mishap has occurred, rather than earlier, thereby helping the health care centres in fabricating corrective measures more than preventive ones. Therefore, it is of utmost importance especially for health care centers where water quality holds a significant value to implement quantitative forensic tools, to counter the situations like growth of pathogens and other factors which affect the quality and water supply system performance in the health care centers. Kutylowska et al (2013) identified the factors like water quality variations and change in the nature of flow which control the failure causes of water supply systems. Debon et al (2009) illustrate the importance of new techniques to evaluate the performance of water supply systems as these systems contribute a

larger value for its users. Faiella et al (2018) describe the limitation of available methodologies for evaluating the water supply networks. These sources highlight the causes of failures of water systems and then identifies the type of techniques to overcome the causes of failure to ensure the efficient water supply system. Studies carried out by Nemes & Bozikova (2013) focused on the growth of bacteria in the water systems of hospitals and the possible consequences of it. So all these primary studies, carried out till now about the failure causes and its type, either water quality based failures or water supply based failures, depend upon mentioned reasons which demand for the application of forensic based method to counter the water system failures.

Methodologies in practice against countering the causes of water supply failures are insufficient to maintain the performance of whole water supply networks in health care centers. Hence, techniques based up on qualitative and corrective actions should be implemented to ensure the performance of the water supply systems. According to Faeilla et al (2018) current techniques lack the approach of responsive behavior against failures and more focused on the prevention of systems. Moreover, Nemes & Bozikova (2013) in particular focused the implementation of evaluating tools on the problems like growth of pathogens and diseases caused by it in health care centers. These two resources support the dire need of new forensic tools to assess the performance of water systems in the health care centers.

None of the sources actually show the implementation forensic tools used to counter the water system failures in the health care centers which are actually the sub sets of the issues discussed in these sources. But all the studies discussed above show the significance of forensic analysis based tools to figure the primary causes of failures. Therefore, we are studying the implementation of forensic investigation based methods for the assessment of water supply failures in health care centers.

1) Concept of Forensic Analysis

Forensic based investigation is a technique to observe the failure causes of objects under study. In general spectrum forensic analysis is usually explained in terms of forensic based investigations. Methods and results accuracy depend upon the problem under consideration and the types of solution demands. Forensic analysis works with the system in usually a passive way but now a days modern development and advanced tools has emerged this field as a strong platform for providing framework for the future failures. It also provides the framework for taking corrective actions for the future. Danon (2001) explained the application of forensic analysis to evaluate the environmental and ecological issues while Block III (2017) illustrated that forensic based investigation is a tool, when performed on medical devices will provide the clinical perspective of devices failure. These two sources explained the application areas of forensics engineering in two different zones which are environmental and medical devices field. But both sources represent the significance of forensic engineering tools to map out the causes of issues. Edwards. D et al. (2008) took one step forward to explain the complexity of system dynamics in the construction projects and explained forensic investigations as a tool for legal proceedings. For the results to be presented as a document for legal consideration, it demands higher accuracy of results and the dependency level in resolving the construction issues. Furthermore, it also helps to provide the platform to avoid issues which can delay the project delivery time or violates the project scope.

2) Failures of Water Supply Systems in Health Care Centers

While focusing upon the failures a health care center faces, all the potential hazards such as chemical, biological, physical and radiological failures are considered water system failures apart from the generally known water source, water treatment & distribution and service connection &plumbing failures. Nemes and Bozikova(2013) mention about the types of water system failures as insufficient flocculation, contamination at the catchment zone, poor hygiene during repairs, emissions during accidents and so on, while Bigoni et al(2014) mention about stagnation time, aging of pipes, physical-chemical properties of the water supply and types of materials being examples of types of failures. In both the articles, there is a mention about the chemical properties such as pH, alkalinity, dissolved oxygen and total hardness and physical properties such as temperature, flow and velocity, few of the factors which the failures depend upon. Wagner. D et al. (1992) in extreme cold and warm weathers explained the process of deterioration of copper in the water distribution system. Wagner. D et al. (1992) built the narrative to explain this sort of corrosion in water distribution systems of health care centers as a three step process which includes corrosion induced by the already corroded part of the pipe, corrosion induced by the pit of water and corrosion of water by some external agents. This study strongly raises the objection on the performance of water supply pipes in the extreme cold and hot weather which itself suggest that the huge temperature variation is unfavorable condition for the copper to be considered as a material for manufacturing of water supply pipes. These factors when not in the safe and usual range tend to cause corrosion of the pipes, which is the biggest risk factor for water supply failure. Moreover, the process of corrosion is highly dependent on the types of pipes being used and the whole installation network of water supply pipes.

3) **Effect of water system failures on health care centers**

The water system failures affect the hospitals both in their daily processes as well as in the equipments which require water to function normally. Bigoni et al(2014) mentions about its need for water at the hospitals and the processes dependent upon it namely, drinking and food preparation, patients' baths and personal hygiene, laundry services, flushing of toilets, fire prevention system, laboratory services, and cleaning, whereas, Rak and Cieslak(2010) talk about the failures from a general perspective by studying the process of how the consumer is at a loss due to a failure at the catchment area. Ashbolt. J et al (2014) illustrated the effect of generation of biofilms with in the pipe system and possible hazardous effects related to it among which top of the list is the production of E coli K12 bacteria which can cause the several water borne disease through water supply systems. These biofilms layer not only controls the water supply discharge but also can lead up to the severe biological changes in the body of the human which in turn can result in to DNA isolation problems. Ashbolt. J et al (2014) mentioned the sources for the E coli K12 which are potentially different sources in their kinds and should be considered to not to end up having in any water supply system to the community. These all sources discuss the water system failures in term of supply and water quality failures which could start from the catchment area problems to the problems compromising the water quality based upon the bacteria like E coli K12.

Table 1 | Bacterial strains used to check the specificity of the qPCR assay for *E. coli* K12

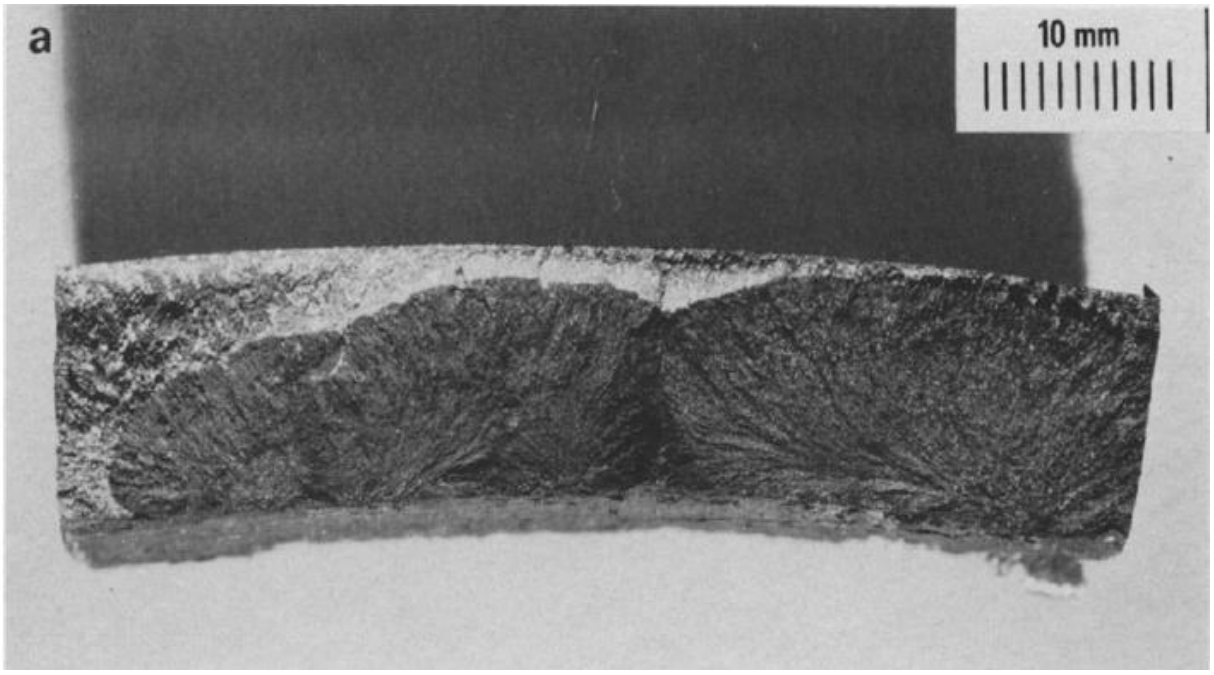
Strains	Source	Strains	Source	Strains	Source
Acinetobacter baumannii	ATCC 19606	*Micrococcus luteus*	ATCC 10240	*E. coli*	EPA isolate 69
Aeromonas hydrophila	ATCC 7966T	*Proteus mirabilis*	ATCC 12453	*E. coli* O157:H7	CDC isolate 302292
Aeromonas hydrophila	ATCC 7966	*Proteus vulgaris*	ATCC 29905	*E. coli* O157:H7	Dairy isolate #1
Aeromonas cavae	ATCC 15468	*Pseudomonas aeruginosa*	ATCC 10145	*E. coli* O157:H7	Dairy isolate #5
Bacillus cereus	ATCC 10876	*Salmonella enteriditis*	ATCC 13076	*E. coli* O157:H7	Dairy isolate #6
Burkholderia cepacia	ATCC 25416	*Serratia marcescens*	ATCC 14756	*E. coli* O157:H7	TX N6021-1, Btype2113
Burkholderia cepacia	ATCC 25416	*Serratia marcescens*	ATCC 13880	*E. coli* O157:H7	TX N6114-2, Btype2521
Campylobacter jejuni	ATCC 29428	*Shewanella putrefaciens*	ATCC 49138	*E. coli* O157:H7	WI N009-6-1, Btype
Citrobacter freundii	ATCC 4391	*Shigella sonnei*	ATCC 25931	*E. coli* O157:H7	ATCC 43889
Citrobacter freundii	ATCC 8090	*Shigella sonnei*	ATCC 9290	*E. coli* O157:H7	ATCC 35150
Enterobacter aerogenes	ATCC 13048	*Staphylococcus aureus*	ATCC 25923	*E. coli* O26	ATCC 12795
Enterobacter aerogenes	ATCC 13048	*Staphylococcus aureus*	ATCC 25923	*E. coli* O111	ATCC 35327
Enterobacter cloacae	ATCC 13047	*Streptococcus pyogenes*	ATCC 19615	*E. coli*	ATCC 51813
Enterococcus faecalis	ATCC 29302	*Yersinia enterocolitica*	ATCC 23715	*E. coli*	ATCC 25922
Enterococcus faecalis	ATCC 19433	*Escherichia coli*	EPA isolate 8	*E. coli*	ATCC 11229
Enterococcus faecium	ATCC 19434	*E. coli*	EPA isolate AD#1	*E. coli*	ATCC 43651
Lactobacillus acidophilus	ATCC 314	*E. coli*	EPA isolate 58	*E. coli*	ATCC 10407
Klebsiella oxytoca	ATCC 13182	*E. coli*	EPA isolate 59	[a]*E. coli* K12, DH1	ATCC 33849
Klebsiella pneumoniae	ATCC 13882	*E. coli*	EPA isolate 62	[a]*E. coli* K12, MG1655	ATCC 700926
Klebsiella pneumoniae	ATCC 31488	*E. coli*	Ohio river isolate R-6	[a]*E. coli* K12 W3110	ATCC 27325
Listeria monocytogenes	Scott O2	*E. coli*	EPA isolate 66		

[a]Test for K12 specific assay positives shown with gray shading

The above quantitative data suggest the strains already declared by EPA (Environmental protection agency) and other source traces from the dairy products. The above table shows the E coli based strains which leads to the biofilm formation and hence compromising the water quality and supply issues.

4) **Relationship between prevention of water system failures and health care centers**

It is imperative to know that water borne diseases in the hospitals can lead to the health situations for which the healthcare centers are actually operating. With Bigoni et al,(2014) stating that the most common health risk associated with drinking-water comes from fecal contamination, it is seen as Rak and Tchórzewska-Cieślak(2010) agree with them, as they too mention about fecal contamination, in the severity of threats list, topping the list with a point weight of 10, indicating that it a very dangerous risk factor. Lenz . Both the articles enumerate the main causes for water supply contamination in health care centers with microbiological contamination considered as the highest risk factor. E et al (1986) explained the term of strain induced corrosion cracking (SICC) which is the result of different corrosion related phenomenon and can be considered in generating solution by changing the water supply conditions for the supply pipes and also by changing the thickness of the pipes. While Nemes and Bozikova(2013) list the causes for water system failures in health care centers as new emerging diseases & pathogens, aging infrastructure and deliberate contaminants, Bigoni et al, (2014) focuses on the corrosion of water pipes, which is caused as a byproduct of the aging process. Both the articles include microbiological factors as the primary risk factors whereas Bigoni et al(2014) additionally includes chemical properties as well. These all sources relates the generation of biofilms in the water supply pipes due to bacterial based strains and thus leading to the inefficiency of water systems. Also, as Fakler et al(2007) explain the relationship of failures and health care centers, it is seen as an organizational and structural mismanagement which may be accentuated by unpredictable individual human failure as well.



Lenz. E et al (1986) in his study generated the images to explain the strain induced corrosion cracking in water supply pipes and then figured out the parameters to be considered which involves to change the physical conditions of the pipe and the condition of the flow.

5) Limitations of failure evaluation techniques

Generally speaking the methods which are in practice to evaluate performance of water supply system only explain the actions to prevent the system from particular type of failures pre considered rather than suggesting the whole framework for taking responsive actions. Faeilla et al (2018) explained that methodologies currently being used are more often concerned about the preventive actions and less inclined towards taking the corrective actions in case of failure occurs while on the other hand, Debon et al (2008) highlighted there are some classical reactive strategies available to counter the situation but these techniques are not sufficient to maintain the performance of the water supply network. Block III (2017) ruled out the other techniques in tracking the instrumental failure of medical devices by building the narrative that forensic based

investigation is a strong investigative tool to figure out the proximate causes of failure which can lead to the production of reports for devices designers so the companies can know much about the common types and causes of failures. So, for these failures to be identified correctly and for the future framework to take active actions against such kinds of failures highly require the methods based upon the forensic engineering investigations rather than conventional or classical methods available for corrective actions.

6) Different Failure Evaluation Methods

Currently, the method used to evaluate the failures is the conventional FMEA. FMEA is generally defined as “Failure Mode & Effect Analysis” which suggest that it seems to be a passive way of responding towards failure but in actual this technique is based up on the forensic investigative tools which cover the domain of not only outlining the causes of failures under study but also providing the framework which, if followed can encourage the concept of safe designs. Concept of Failure Mode & Effect Analysis is based up on the concept of risk evaluation and modern risk assessment techniques. There are a few investigation techniques such as healthcare focused approach of FMEA (HFMEA – Healthcare Failure Mode Effects Analysis) with human factor- focused (SHERPA - Systematic Human Error Reduction and Prediction Analysis) and system-focused (STAMP - Systems-Theoretic Accident Model and Processes) approaches, which are the ones to be used in the future for better evaluation results. While Rak and Cieslak (2010) define FMEA as a technique for determining the ways in which equipment can fail and the consequences of the failure on reliability and safety, Faiella et al(2018) defines HFMEA as a systematic risk assessment method derived from high risk industries to prospectively examine complex healthcare processes, showing the importance of the FMEA technique in healthcare units. According to Faiella et al (2018),SHERPA supports the study of

human-based processes and STAMP-STPA improves the causal analysis. This statement is similarly mentioned by Rak and Cieslak(2010) by stating that the investigative methods are to analyze the possibility of system failures in the design and production stages with SHERPA's focus being on health care related failures. Lio. C et al (2011) explained the performance domain and area of application of traditional FMEA which he considered Failure Mode & Effect Analysis to be a technique which acts as a passive tool in highlighting the type of failures while performing the high standard medical operations. SHERPA is based upon the pure active technique rather than traditional FMEA which records responses after the failures and provide framework for future design issues.

Table 1
A comparison of three commonly used safety analysis techniques.

Item	FMEA	FTA	HAZOP
Nature	Qualitative analysis	Qualitative and quantitative analysis	Qualitative analysis
Mode	Induction	Logical deduction	Structured
Form	Table	Tree structure	Table
Time	Single time	Single time	Continuous
Failure condition	Single point of failure	Multi-point failure	Single point of failure
Use opportunity	Design phase	Any phase	Design phase
Application system	Non-complex system	Complex system	Non-complex system
Human factor	Do not consider human error	Consider human error	Consider human error
Advantages	• Systematization • Easy to update • Sort of serious accidents • Simple and easy to understand	• Inference of accident results • Cause identification	• Systematization • Easy control • Hazard identification process • Team approach, stimulating imagination • Simple and easy to understand
Disadvantages	• Suitable for hardware analysis • Operating environment factors analysis not included • Some hazards may be missed due to single-point failure mode • The root cause failure is not shown directly	• Cannot fully identify all the causes of failure • Analysts need be trained • More time and cost are required for complex systems	• Lack of quantitative data • Longer time • Many professionals are required

The above qualitative data was explained by Liao. C et al (2011) to show the comparison between FMEA and other techniques, which serves the same function other than only qualitative analysis.

7) **Viability of forensic analysis in the future**

Forensic Investigations are generally based up on the advanced set up to outline the causes of failure on the basis of which a network can be designed afterwards. Factor of safety for the design gets improved under forensic analysis so there is no further requirement left to invest a lot to improve the design for safety purposes. Debon (2008) explained that forensic proactive techniques predict the best measures to take for the reason these predictions are based upon actual risk models while Danon (2001) moved one step forward and explained that the forensic investigations are not only feasible for determining the type of damages that can occur but also the extent of damages under different conditions. These two researchers conclude the significance of forensic engineering tools but the proactive techniques are more cost effective in terms of avoiding the damages.

8) Results & Conclusion

Forensic based investigation is an investigative tool to highlight the causes of water system failures. Health care centers do need the implementation of forensic based tool in different weather conditions to perform efficiently. Forensic engineering designs are free from the repetitive failure causes. Strain Induced corrosions in the water supply pipes of health care centers need forensic examination in order to map out the physical parameters of the pipes. Water borne diseases in the hospital are mostly the result of corrosion of pipes under different atmospheric conditions.

Pathogens in the water supply system of hospitals should be pre traced before regulating the flow of water across the health care centers for multipurpose. FMEA

can be applied as a strong forensic tool to identify the factors which compromise the performance of water supply pipes in health care centers.

References:

1. Bigoni. R., Sorlini. S., Collivignarelli. M. C., & Berbenni. P. (2014). *Drinking water quality assessment and corrosion mitigation in the hospital water supply system of Chacas Village (Peru).* Ambiente & Água - An Interdisciplinary Journal of Applied Science. Vol 9, Issue 3. 379-389p. DOI: 10.4136/ambi-agua.1407

2. Block, F.E. (2017). *The Role of Forensic Engineering Investigations in Medical Device Reports*. Journal of Clinical Engineering, *42(2)*, 85-88. doi: 10.1097/jce.0000000000000208

3. Danon-Schaffer. M. N (2010) *Walkerton's Contaminated Water Supply System: A Forensic Approach to Identifying the Source*, Environmental Forensics, 2:3, 197-200, DOI: 10.1006/enfo.2001.0054

4. Debón. A., Carrión. A., Cabrera. E., & Solano. H.(2009). *Comparing risk of failure models in water supply networks using ROC curves*. Retrieved April 04, 2018, from https://www.sciencedirect.com/science/article/pii/S0951832009001926

5. Faiella. G., Parand. A., Franklin. B. D., Chana. P., Cesarelli. M., Stanton. N. A., & Sevdalis. N.(2018). *Expanding healthcare failure mode and effect analysis: A composite proactive risk analysis approach*. Reliability Engineering and System Safety. Vol 169 , 117 – 126p.; DOI: http://dx.doi.org/10.1016/j.ress.2017.08.003

6. Kutyłowska. M., & Hotloś. H.(2013).*Failure analysis of water supply system in the Polish city of Głasgów*. Retrieved April 04, 2018, from https://www.sciencedirect.com/science/article/pii/S1350630713002471

7. Nemeš. P & Božiková. J.(2013) *Risk Analysis and Risk Management in Water Supply System Sector* . Issue – 15. 217 – 222p. ISSN-1584-5990

8. Rak. J. &Tchórzewska-Cieślak. B. (2010) *The Possible Use of the FMEA Method to Ensure Health Safety of Municipal Water,* Journal of KONBiN .Vol. 14-15, Issue 1. 143 – 154p DOI: 10.2478/v10040-008-0173-9

9. Ho, C. C., & Liao, C. (n.d.). The use of failure mode and effects analysis to construct an effective disposal and prevention mechanism for infectious hospital waste. Retrieved from http://booksc.org/book/17173255/a49b4e

10. Erve, M., et al. “Provisions to Prevent Strain-Induced Corrosion Cracking in Ferritic Piping Systems of Boiling Water Reactors.” M. Erve; W. Brettschuh; N. Henzel; H. Spörl; E. Lenz | Download, booksc.org/book/2309040/79c655

11. Fischer, W., et al. “Copper Deterioration in a Water Distribution System of a County Hospital in Germany Caused by Microbially Induced Corrosion – I. Description of the

Problem." W. Fischer; H. H. Paradies; D. Wagner; I. Hänßel | Download, booksc.org/book/1710832/7da16a.

12. Lu, et al. "Development of an Escherichia Coli K12-Specific Quantitative Polymerase Chain Reaction Assay and DNA Isolation Suited to Biofilms Associated with Iron Drinking Water Pipe Corrosion Products." Lu, Jingrang; Gerke, Tammie L.; Buse, Helen Y.; Ashbolt, Nicholas J. | Download, booksc.org/book/43487769/10c8a2.

13. Forensic Project Management: An Exploratory Examination of the Causal Behavior of Design-Induced Rework - IEEE Journals & Magazine, ieeexplore.ieee.org/abstract/document/4494738/.

14. Fakler, J.K., Robinson, Y.,Heyde, C.E.,& John, T.,(2007). Volume 1; Issue 5; 1 – 5. *Errors in handling and manufacturing of orthopaedic implants: the tip of the iceberg of an unrecognized system problem? Patient Safety in Surgery.* Retrieved from https://pssjournal.biomedcentral.com/articles/10.1186/1754-9493-1-5

15. Vykopalová,H., Cupal,M.,(2014). *Forensic Engineering and the Importance of the Human Factor, Procedia - Social and Behavioral Sciences*. Vol. 116, 1665-1669. Retrieved from https://doi.org/10.1016/j.sbspro.2014.01.453