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BENEFIT/COST MODEL FOR NOISE LOGGERS' DISTRIBUTION - CITY OF MONTREAL

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Abstract: One billion individuals worldwide do not have access to clean drinking water. According to Canadian Infrastructure Report of 2016, Canada's water network is in a declining state, which significantly increases the risk of sudden pipes' breaks. The average processed water loss due to leaks in the city of Montreal is one of the highest among other Canadian cities with 23% losses. Accordingly, early leak detection and repair will help reduce those huge water losses and keep the water infrastructure sustainable. Thus, this paper proposes a benefit-cost analysis to investigate the potential benefits of expanding the acoustic noise loggers' coverage over 50% network as opposed to the manual (crew-based) leak detection. Those benefits include (1) risk savings in terms of smaller number of leaks, water losses, and breaks; (2) monetary savings in both direct and indirect costs; and (3) temporal savings in terms of time spent to detect and repair the network leaks. To compute those benefits, a framework that functions through five integrated models was built: (1) central database that contains several datasets (i.e. asset inventory, leak detection types, leak repair temporal and financial, network data); (2) leak detection systems' financial models that compute the CAPEX and OPEX of the manual and noise loggers leak detection systems; (3) leaks simulation model that simulates the appearance of different leak categories among different street categories; (4) leaks temporal and financial models that estimates the temporal and financial implications of the leaks for both systems (i.e. repair time/cost, water losses, etc.); and (5) risk model that calculates the probability and consequences of breaks among different street categories. The framework was applied on Montreal's water network and the analysis was carried out on both leak detection systems across 20 years planning horizon. The results displayed huge savings for the noise loggers 50% expansion scenario.

1 INTRODUCTION

The infrastructure is at risk. The Canadian population for example has doubled in 40 years from 17.9 million in 1960 to reach 35.1 million in 2013 and expecting to be 42.5 million by 2056 (Statistics Canada 2015). The annual population growth rate for the period between 1990 and 2010 was 1%. Moreover, the natural increase of population was also attributed to a heavy inflow of rural migrants. The migration towards Canada has been mainly due to the employment opportunities and the major proportion of services it provides. Due to their attractiveness and extremely high population density, various cities were targeted for residency during the first half of the century. However, they lost their attracting elements in the second half of the twentieth century because of the accumulating residency overload and inability to expand their existing infrastructure.

In more specific context, access to drinking water, which is essential for living, is not fully granted where; around one billion individuals worldwide do not have access to clean drinking water (Krchnak 2016). For existing water distribution systems, leaks lead to potential water losses that can reach 20% to 30% of the processed water, and it can even surpass 50% of the processed water in some systems (Cheong 1991 and AWWA 2009). The leaks' contribution has been estimated at about 70% of the water losses within the network and this percentage is likely to increase in areas with low maintenance (Van Zyl 2007). Those losses don't only stop at the cost of the processed water, but they also create social and environmental problems, which could be translated into financial losses as well. For instance, the annual cost of the leak damages is estimated at 7£ billion; where 1.5£ billion is considered to be direct damage costs, and 5.5£ billion is considered to be social impact costs (Royal et al. 2011). Unattended leaks are susceptible to grow and thus allowing the introduction of pathogens and contaminants from the surrounding environment, which results in a major decrease of the quality of the water provided and might cause harmful impacts on human life and other beneficiaries (Alkasseh 2013).

Several scholars developed a risk assessment model for water distribution networks. The model supported the city officials in identifying and prioritizing the pipes that need rehabilitation or replacement through reliable, up-to-date water distribution data from their city. Moreover, it simplified the allocation of capital funds for future pipe improvement projects as the city continues its urbanization (Devera 2013). According to environment Canada report in 2011, the average water loss in water networks equals to 13% with the maximum value in Quebec with 21%. The main source of those water losses was the leaks in the water distribution network components. The early detection of leaks in the water network alongside with undertaking timely intervention actions before any unexpected failures in the network will attain several beneficial returns to municipality that can be summarized as follows: (1) reduce the life-cycle operating costs, (2) improve the intervention plans, (3) decrease the break occurrence risk and hence reduce the assets damage risk, and 4) increase the consumers' confidence in the water utility (Government of Canada 2017).

Other scholars employed empirical analysis of the economic, environmental and social consequences of large-diameter water main failures to estimate their overall impact cost. The model aids in predicting the future water main failure consequences to enable risk-based, long-term capital improvement planning of water supply systems (Kalyan 2015). Furthermore, scholars evaluated new leak detection and measurement technologies to determine actual facility fugitive emission rates. The results of this study help the cities in evaluating the different leak detection technologies (Trefiak 2006). Another study was conducted to investigate the different leak detection technologies and quantify the benefits of installing acoustic leak detection technology. The investigation used state of the art noise correlation and computer correlation technology to survey the distribution system mains. The model displayed that 80% of housing units had leaks and it showed that the leak detection equipment will enhance the network performance and decrease the number of leaks (Scolze and Maloney 1995). Finally, scholars developed a benefit-cost analysis for the leak detection. The study was implemented in New Mexico water systems and it showed the potential of real water savings. The scholars used the International Leakage Index (ILI) as a performance indicator for real losses in a water network. The main goal behind implementing advanced leak detection methods is minimizing the time required to detect a leak, and accordingly reduce the real water losses and avoid the occurrence of costly major breaks (Hardeman 2008). Even though, previous scholars developed leak detection models, they failed to consider the leak propagation to visualize the leak advancement stages until the pipe breaks. Furthermore, they did not develop an inclusive benefit/cost (B/C) analysis models that simulates the leaks appearance and propagation, computes the water losses, financial losses (water losses, repair, consequences of failure), temporal losses, and number of leaks and breaks.

2 OBJECTIVES

This paper aims at developing a Benefit/Cost (B/C) analysis to investigate the impacts of expanding the coverage of the noise loggers leak detection system besides the manual detection system to ensure early detection of the leaks.

3 METHODOLOGY

The B/C analysis model framework revolves through five phases as shown in Figure 1. The phases could be summarized as follows: (1) central database that incorporates the data provided by the city of Montreal as well as the model assumptions needed to build the B/C analysis, (2) systems financial model that computes the capital and operational expenditures (CAPEX and OPEX) of both the manual and noise loggers leak detection system, (3) leaks simulation model that simulates the different leak categories appearance among the different street categories, (4) leaks temporal and financial models that computes the temporal and financial implications of the leaks in both the manual and noise loggers leak detections systems (i.e. repair time and cost, water losses, water losses costs, etc.), (5) risk model that computes the probability and consequences of breaks for different street categories.

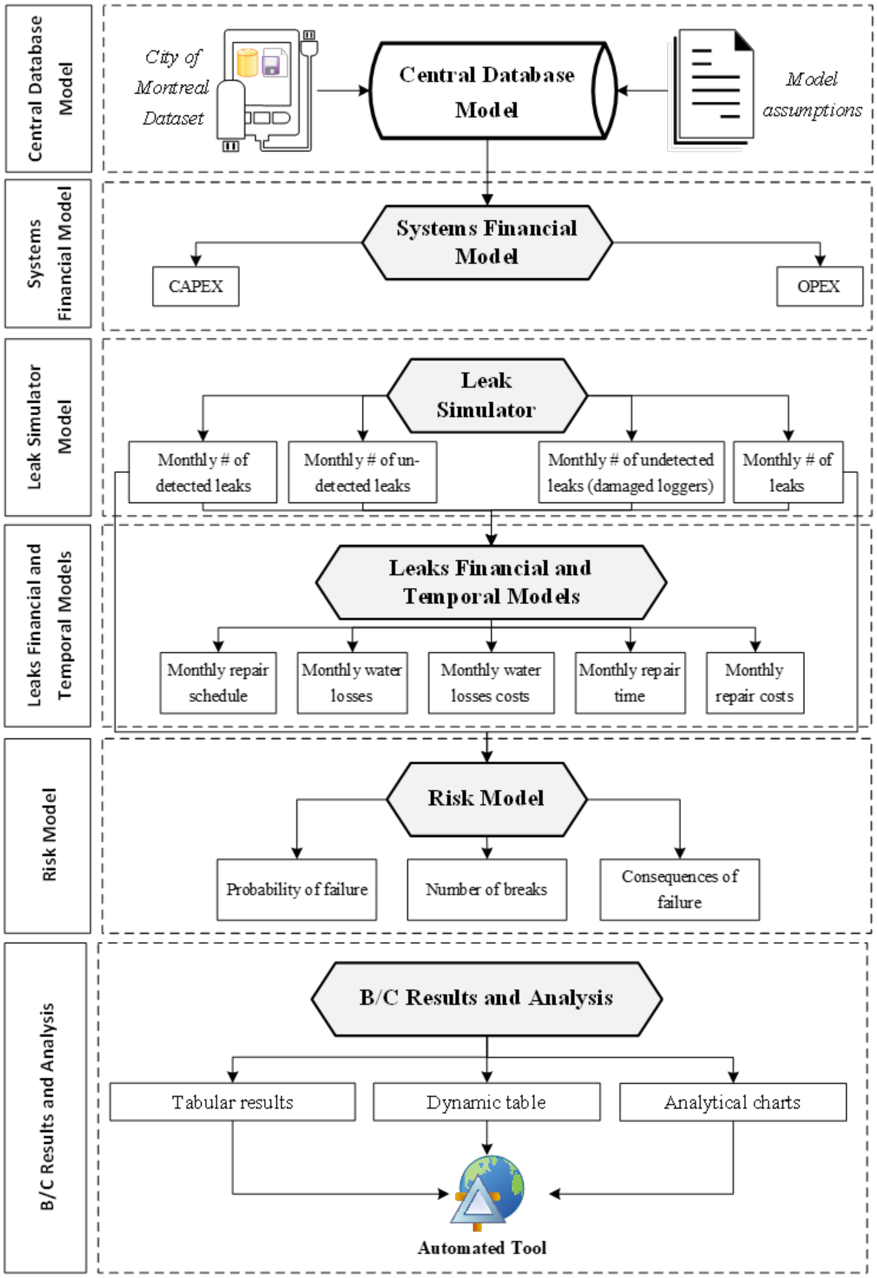

Figure 1: Methodology

The central database model is the foundation of the system that collects the different sources of data to build the B/C analysis. The systems' financial model is the financial model that that computes the capital and operational expenditures of both the manual and noise loggers leak detection system. It extracts all the systems' related data from the systems' related cost and productivity dataset. Then, separate models were developed for each leak detection system due to the existence of different cost centers. The leak simulation model is the core computational model that feeds the risk and the leaks financial and temporal models. The leak simulator simulates the appearance of each leak category in the different street categories. It extracts the number of annual leaks for each leak category and the probability of detection from the leak categories-related dataset and the repair frequency, repair cost, repair time, and percentage repair for each street category from the repair and maintenance dataset. Then, based on the extracted data, it builds the leak simulation dataset for both the manual and noise loggers leak detection systems. Thenceforth, it computes the annual number of leaks per leak category per street category, based on both the total number of annual leaks and the percentage of each street category from the network under study. Hence after, depending on the leak detection system, it either computes the number of active and damaged noise loggers for the noise loggers leak detection system or extracts the probability of detection for the manual leak detection system. The leak financial and temporal models are the heart of the B/C analysis system that computes the financial, environmental, and temporal implications of different leak categories on the street categories. Similar to the leak simulation model, the leak financial and temporal models are built for both the manual and noise loggers leak detection systems, based on the desired coverage area of each system. Through a pre-set leak repair schedule, the model monthly calculates the water losses, repair and processed water losses cost, repair time per leak category within each street category. It extracts the information from three sources as follows: (1) monthly detected and undetected leaks for both the manual and noise loggers leak detection systems, which are extracted from the output of the leak simulation model discussed earlier in the previous section, (2) repair frequency, percentage repair (%), repair time, and repair cost, which are obtained from the repair and maintenance-related dataset, and (3) average monthly water losses per leak category, and processed water unit cost, which is attained from the leak categories-related dataset. Then, based on the monthly detected leaks, repair frequency, and percentage repair (%), the model calculates the repair schedule per leak category within each street category separately to account for the criticality of street/leak categories over others. Hence after, based on the repair schedule along with the repair time and cost, the model determines the repair time and cost that are needed to successfully complete the leak repair. In parallel, based on the number of un-detected and un-repaired leaks, the model computes the amount of water losses and accordingly, based on the processed water unit cost, the water losses associated costs. Finally, the risk model is one of the core financial models in the B/C analysis that computes the probability and consequences of failure for each street category and leak detection system. The model collects its' data from the risk-related dataset in the central database model and the outcome of the leak simulator, represented through annual number of unrepaired large leaks.

3.1 Central database module

The central database contains data about the network and the analysis that includes but not limited to the physical network characteristics, repair strategies time and cost, leak propagation rates, manual and noise loggers' leak detection systems' capital investment and operating expenditures across their service lives, interest rate, planning horizon, consequences of failure, etc. Those data could vary from one case to another and the model is flexible to compute the corresponding indicators according to the inputted data.

3.2 Systems' financial module

The systems' financial model is the financial computational model that that computes the capital expenditures (CAPEX) and operating expenditures (OPEX) of both the manual and noise loggers leak detection system. It extracts all the systems' related data from central database. Then, separate models were developed for each leak detection system due to the existence of different cost centers. The main outcomes of the systems' financial models are the CAPEX and OPEX for each system over the planning horizon. The cost categories of each system could be displayed in Figure 2. A sample of the OPEX of the noise loggers leak detection system could be displayed in Equation 1. The other categories were similarly computed for the manual and noise loggers' leak detection systems.

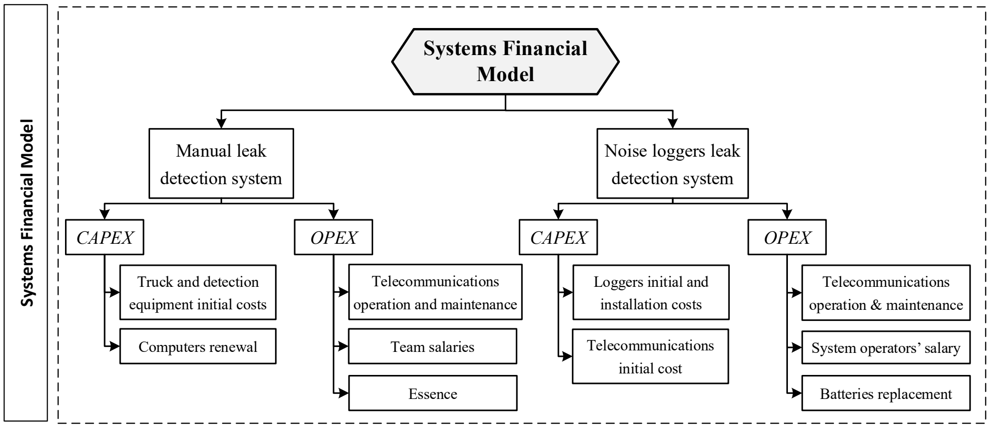

Figure 2: Cost categories for manual and noise loggers leak detection systems

[1] $\mathrm{OPEX_{NLDS}} = \sum_{n=0}^{N}\left[[TMN_n + BR_n + OS_n] * \left[\frac{1-(1+i)^n}{i}\right]\right]$

Where; $\mathrm{TMN_n}$ is the telecommunications (i.e. repeaters and transmitters) maintenance cost at year n (\$); $\mathrm{BR_n}$ is the battery replacement cost at year n (\$); OS_n is the operator salary at year n (\$); i is the annual interest rate (%); n is the counter of the number of compounding periods, which is annual in this study; and $\mathrm{OPEX_{NLDS}}$ is the present worth of the OPEX of the noise loggers' leak detection system that takes place throughout the study planning horizon (\$).

3.3 Leak Simulator

The leak simulation model is the core computational model that feeds the risk and the leaks financial and temporal models. The leak simulator simulates the appearance of each leak category in the different street categories. It extracts the number of annual leaks for each leak category and the probability of detection from the leak categories-related dataset and the repair frequency, repair cost, repair time, and percentage repair for each street category from the repair and maintenance dataset. Then, based on the extracted data, it builds the leak simulation dataset for both the manual and noise loggers leak detection systems. Thenceforth, it computes the annual number of leaks per leak category per street category, based on both the total number of annual leaks and the percentage of each street category from the network under study. Hence after, depending on the leak detection system, it either computes the number of active and damaged noise loggers for the noise loggers leak detection system or extracts the probability of detection for the manual leak detection system. The outcome of the leak simulation model is the number of monthly detected and un-detected leaks for both the manual and the noise loggers leak detection systems. A sample from the number of annual leaks per leak and street category could be displayed in Equation 2. Further computations for the detected and undetected leaks for the manual and noise loggers' leak detection systems were undertaken (Abu-Samra 2017).

[2] $\mathrm{NOL}_{\mathrm{SC}_{LC_{LDS_n}}} = \lim_{\mathrm{n \to N}}\left[\mathrm{TNOL}_{LC_{LDS_n}} * PON_{SC_{LDS}}\right]$

Where; $\mathrm{NOL}_{\mathrm{SC}_{LC_{LDS_n}}}$ is the number of leaks per leak category within each street category in year n. It is computed for each leak detection system separately as it varies according to the desired system coverage scenario; $\mathrm{TNOL}_{LC_{LDS_n}}$ is the total annual number of leaks per leak category in year n. It is computed for each leak detection system separately as it varies according to the desired system coverage scenario; and $PON_{SC_{LDS}}$ is the percentage of each street category from the network, which is computed for each system separately as it varies according to the desired system coverage scenario (%).

3.4 Leaks financial and temporal modules

The leak financial and temporal modules are the heart of the B/C analysis system that computes the financial, environmental, and temporal implications of different leak categories on the street categories. Similar to the leak simulation model, the leak financial and temporal models are built for both the manual and noise loggers leak detection systems, based on the desired coverage area of each system. Through a pre-set leak repair schedule, the model monthly calculates the water losses, repair and processed water losses cost, repair time per leak category within each street category. It extracts the information from three sources as follows: (1) monthly detected and undetected leaks for both the manual and noise loggers leak detection systems, which are extracted from the output of the leak simulation model discussed earlier in the previous section, (2) repair frequency, percentage repair (%), repair time, and repair cost, which are obtained from the central database, and (3) average monthly water losses per leak category, and processed water unit cost, which is attained from the financial dataset. Then, based on the monthly detected leaks, repair frequency, and percentage repair (%), the model calculates the repair schedule per leak category within each street category separately to account for the criticality of street/leak categories over others. Hence after, based on the repair schedule along with the repair time and cost, the model determines the repair time and cost that are needed to successfully complete the leak repair. In parallel, based on the number of un-detected and un-repaired leaks, the model computes the amount of water losses and accordingly, based on the processed water unit cost, the water losses associated costs. The outcomes of the leak financial and temporal models are the monthly and cumulative repair schedule, water losses, water losses costs, repair time, and repair cost. Samples of the repair cost and repair time computations per leak category could be displayed in Equations 3 and 4 respectively. Similar computations were carried out for each leak detection system and category (i.e. water losses, repair time, etc.).

$$[3]\ \mathrm{PVRPC}_{\mathrm{NLDS}} = \sum_{n=0}^{N}\left[\mathrm{RPC}_{\mathrm{SC}_{LC_{NLDS_n}}} * \left[\frac{1-(1+i)^{n}}{i}\right]\right]$$

$$[4]\ \mathrm{RPT}_{\mathrm{SC}_{LC_{NLDS_n}}} = \lim_{\mathrm{n}\to\mathrm{N}}\left[\sum_{t=1}^{t=12}\left[POR_{SC_{LC}} * \mathrm{NODL}_{\mathrm{SC}_{LC_{NLDS_t}}} * RPUT_{SC_{LC}}\right]\right]$$

Where; $\mathrm{RPC}_{\mathrm{SC}_{LC_{NLDS_n}}}$ is the repair cost per leak category within each street category for the noise loggers' leak detection system at year n (\$); $\mathrm{PVRPC}_{\mathrm{NLDS}}$ is the present worth of the repair cost of the noise loggers' leak detection system throughout the study planning horizon (\$); and $\mathrm{RPT}_{\mathrm{SC}_{LC_{NLDS_n}}}$ is the repair time per leak category within each street category for the noise loggers' leak detection system at year n (hours).

3.5 Risk module

The risk model is one of the core financial modules in the B/C analysis that computes the probability and consequences of failure for each street category and leak detection system. The model collects its' data from the central database model and the outcome of the leak simulator, represented through annual number of unrepaired large leaks. The outcome of the risk model could be summarized into two indicators as follows: (1) number of breaks, and (2) consequences of failure. The number of breaks and annual consequences of failure varies among the leak detection systems and street categories. They could be computed as shown in Equations 5 and 6 respectively.

$$[5]\ \mathrm{NOB}_{\mathrm{NLDS}_n} = \lim_{\mathrm{n}\to\infty}\left[PODN_{NLDS} * POBO_{SC} * NOLL_{n}\right]$$

$$[6]\ \mathrm{ACOF}_{\mathrm{NLDS}_n} = \lim_{\mathrm{n}\to\mathrm{N}}\left[\mathrm{NOB}_{\mathrm{NLDS}_n} * COF_{SC}\right]$$

Where; $\mathrm{NOB}_{\mathrm{NLDS}_n}$ is the annual number of breaks per street category in the noise loggers leak detection system in year n; and $\mathrm{ACOF}_{\mathrm{NLDS}_n}$ is the annual consequences of failure per street category in the noise loggers leak detection system in year n (\$).

3.6 B/C computation module

The B/C computation module aims at computing the savings of the financial, temporal, and risk modules between the current and the baseline scenarios. In this study, the current scenario refers to “50% of the network covered by noise loggers leak detection system and the other 50% of the network covered by manual leak detection system”. However, the baseline scenario refers to the “100% of the network covered by manual leak detection system and 0% of the network is covered by noise loggers leak detection system”. The financial results were computed, taking the time value of money into account over the planning horizon. However, the temporal and leaks and breaks categories were directly summed up over the planning horizon. Then, they were split for each leak detection system to enable the user to visualize the implications of each leak detection system separately. Hence after, they were sub-categorized, depending on their category (i.e. financial ➔ CAPEX, OPEX, risk, water losses, and repair cost; temporal ➔ repair time; and leaks and breaks ➔ leaks, and breaks). Finally, they were broken up for each street category and separated for each leak category. The savings are computed for each attribute through Equation 7.

$$[7]\ ATB_{savings} = \frac{\mathrm{ATB}_{baseline} - \mathrm{ATB}_{current}}{\mathrm{ATB}_{baseline}}$$

Where; $ATB_{savings}$ is the attribute/category savings of the current over the baseline scenario (%); $\mathrm{ATB}_{baseline}$ is the attribute/category results in the baseline scenario (varies); and $\mathrm{ATB}_{current}$ is the attribute/category results in the current scenario (varies).

4 RESULTS AND ANALYSIS

To demonstrate the systems’ functionality, the system was applied to 3,500 Km water network of the city of Montreal as displayed in Figure 3. The analysis was done over a period of 20 years. The interest rate was assumed at 2%. The physical pipes characteristics as well as the financial maintenance costs and the consequences of failure were obtained from the city of Montreal (Ville de Montreal 2017). The results have been categorized into three main parts as follows: (1) temporal results, (2) leaks and breaks analysis, and (3) financial results.

Figure 3: Noise loggers leak detection interface – City of Montreal

4.1 Temporal savings

The current scenario resulted in 158k hours in leaks repair over the planning horizon compared to 263k hours over the planning horizon for the baseline scenario, which implies about 40% savings in the leaks repair time, as shown in Table 1 and Figure 4. The temporal savings resulted from earlier detection of the leaks and thus, taking early actions accordingly. For the leak detection systems percentage contribution in the current scenario, the manual leak detection system resulted in 90k hours for repairing the leaks over the planning horizon, compared to 68k for repairing the leaks over the planning horizon of the noise loggers leak detection system, which implies about 25% extra time for the manual detection system. The percentage contribution of the manual leak detection system is 57% compared to 43% for the noise loggers leak detection system. Thus, even though both systems are equally distributed over the network, the overall repair time of the manual detection system exceeds the noise loggers leak detection system by about 22k hours over the planning horizon.

4.2 Leaks and breaks savings

The current scenario displayed around 13k leaks and 560 breaks over the planning horizon compared to 26k leaks and 4k breaks over the planning horizon for the baseline scenario, while implies about 57% savings, as shown in Figure 4. Those savings are obvious in both the temporal and financial categories, as the more the number of leaks and breaks, the more time the leak repair team will put to repair them and more money accordingly, due to the high consequences of failures for repairing the leaks and breaks.

4.2 Financial savings

The current scenario displayed $308 million over the planning horizon compared to $415 million over the planning horizon for the baseline scenario, which implies about 26% savings, as shown in Table 1 and Figure 4. The model accounts for the following cost centers: (1) CAPEX for noise loggers and manual leak detection systems, (2) OPEX for noise loggers and manual leak detection systems, (3) costs resulting from water losses, due to the leaks, (4) leaks repair cost, and (5) consequences of failure, resulting from the breaks that occurred either due to unrepaired large leaks or undetected large leaks. Furthermore, it is worth mentioning the distribution of the cost over those cost centers where; the costs of the CAPEX, OPEX, water losses costs, leaks repair cost, and consequences of failure are $28 million, $37 million, $14 million, $223 million, and $5 million respectively. It is obvious that the leak repair cost contributes with 72%, followed by the OPEX, which contributes with 12%. Then, they are followed with the CAPEX, which contributes with 9%. In addition, the consequences of failure and the water losses costs are at the bottom of the list with about 5% and 2% respectively. This means that the extra spending on the CAPEX and OPEX for expanding the coverage of the noise loggers is a worthy investment, even if it costs more than the manual leak detection system. The reason why is because the extra cost paid on the system CAPEX and OPEX represents about 21% from the overall cost. However, the savings resulting from instantly detecting the leaks and thus repairing them, before reaching critical stages, is way more than the extra cost paid on the installation and operation of the noise loggers' leak detection system. The CAPEX and OPEX of the current scenario over the planning horizon was estimated at $85 and $75 million respectively, compared to $29 and $2 million respectively for the baseline scenario, which implies about 200% and 350% extra money paid for the installation and operation of the leak detection systems respectively. For the leaks repair cost, the current scenario displayed $223 million for repairing the leaks over the planning horizon, compared to $345 million for repairing the leaks over the planning horizon for the baseline scenario, which implies about 35% savings. This shows that the monetary value of savings resulting from early detecting the leaks and repairing them accordingly is about $122 million, compared to a total of $37 million, resulting from both the CAPEX and OPEX, which is about 3 times more savings, just from the leak repair cost center. Similarly, for the consequences of failure, the current scenario displayed $5.2 million as a result of breaks taking place over the planning horizon, compared to $11.2 million as a result of breaks taking place over the planning horizon for the baseline scenario, which implies about 53% savings. Those savings occurred as a result of instantly detecting the leaks and undertaking necessary leak repair actions accordingly. The savings are estimated at $6 million compared to the $37 million, resulting from both the CAPEX and OPEX, which contributes to about 16% from the CAPEX and OPEX. Finally, for the cost of the water losses, the current scenario displayed $14 million for the unrepaired or undetected leaks compared to $30 million for the unrepaired or undetected leaks of the baseline scenario, which implies about 53% savings. Those savings occurred because of instantly detecting the leaks and thus, saving the environment as well as the processed water cost. The savings are estimated at $16 million, compared to $37 million, resulting from both the CAPEX and OPEX, which contributes to about 43% from the CAPEX and OPEX. In summary, it is obvious that the current scenario saves about 26% compared to the baseline scenario because it minimizes the number of undetected and unrepaired leaks, saving millions in the leak repair and consequences of failure compared to the extra cost paid on the installation and operation of the noise loggers leak detection system.

For the leak detection systems percentage contribution in the current scenario, the manual leak detection system resulted in $170 million over the planning horizon for the CAPEX, OPEX, water losses costs, leaks repair cost, and consequences of failure, compared to $139 million over the planning horizon for the CAPEX, OPEX, water losses costs, leaks repair cost, and consequences of failure of the noise loggers leak detection system, which implies that there are 18% savings in favor of the noise loggers leak detection system. The percentage contribution of the manual leak detection system is 55% compared to 45% for the noise loggers leak detection system. Thus, even though both systems are equally distributed over the network, the overall cost of the manual detection system exceeds the one of the noise loggers leak detection system by about $31.2 million over the planning horizon. This is due to extremely high leaks repair and water losses' costs.

Table 1: Summary B/C analysis results

Category	Scenario	Category - Total
Financial	Current	$ 308,653,046.74
Financial	Baseline	$ 415,197,279.91
Temporal	Current	157,918
Temporal	Baseline	263,746
Leaks & Breaks	Current	13,093
Leaks & Breaks	Baseline	30,112

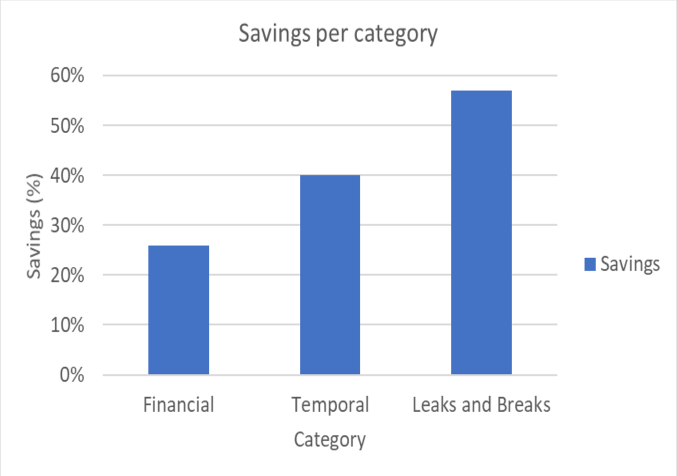

Figure 4: Savings per category

5 KEY FINDINGS AND CONCLUSIONS

The key findings could be summarized as follows:

1. The CAPEX and OPEX of the noise loggers don't highly contribute to the overall life-cycle costs as they contribute with 21% only.
2. The leaks repair cost center tops the list of contributors with 72% ($206.5 million), followed by water losses 12% ($17.5 million), and consequences of failure 5% ($6.7 million).
3. The temporal, financial, and leaks and breaks savings of the current scenario over the baseline scenario were 40%, 26%, and 57% respectively.
4. The noise logger's scenario displayed 57% less leaks and breaks compared to the baseline scenario due to the earlier leak detection and repair accordingly.
5. The noise loggers' scenario displayed 106k hours less than the baseline scenario, saving about 40% savings in the leaks repair time.
6. The annual water losses worth for the noise loggers' scenario is estimated at $600,000 per year. However, the annual water losses worth for the baseline scenario is estimated at $1.25 million per year. Thus, the annual savings are estimated at $625,000, which is 50% savings.

In conclusion, the B/C analysis showed that expanding the coverage of the noise loggers leak detection system is a worthy investment that will result in huge temporal and financial savings over the planning horizon. Even through, it seems to cost more at the first glance when looking at the CAPEX and OPEX, but they do not highly contribute to the overall cost where; they represent 21% from the overall cost. Thus, it is recommended to consider expanding the coverage of the noise loggers leak detection system over the city of Montreal water distribution network to detect the leaks in a timely manner and thus allow the leak repair teams to repair the leaks before they propagate and become a break, which results in huge financial, social, and environmental losses. Although this paper is a good starting point for quantifying the in-tangible benefits to support decision-makers in their decisions but, data-driven models could be used to enhance the leak simulator model’s accuracy. Furthermore, probabilistic modelling could be used for modelling the risk.

6 ACKNOWLEDGEMENTS

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