TRIZ Inventive Solution in Solving Water Pipeline Leakage Using Accelerometer Sensor

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***Abstract*—To a developing country, sustaining a consistent water supply for industrial and domestic usages is a great challenge. In Malaysia, this can be demonstrated by the alarming rate of the Non-Revenue Water (NRW), which is >30% and this is greater than the recommended NRW by the World Bank. Therefore, this paper highlights several causes that lead to this and determines the primary cause, which is water pipeline leakage. The Teoriya Resheniya Izobretatelskikh Zadatch (TRIZ), a problem-solving tool is employed to study the potential solutions. Then, the water system testbed is developed to examine the performance of the proposed solution.**

***Index Terms*—TRIZ; Inventive Problem Solving; Water Pipeline**.

I. INTRODUCTION

Any engineering field may have its own engineering problems. As part of continuous effort to attain creative and practical solutions, several tools such as Soft Systems Methodology (SSM), Appreciative Inquiry, TRIZ and Simplex have been introduced and employed in the problem-solving process. Among these tools, TRIZ is found to be more suitable [1]-[7] compared to the others.

TRIZ is abbreviated from the Russian term, which is known as Theory of Inventive Problem Solving, is a systematic and ingenious problem-solving method [1][2]. The concept of TRIZ is to solve a real problem using innovative and systematic solutions for both process and product. TRIZ is employed to solve the key issue of high Non-Revenue Water (NRW) in our project. NRW has been introduced as one of the water operator's Key Performance Indicator (KPI) by the Water Services Council of Malaysia (SPAN) to measure the sustainability of water services. NRW index for the past four years of 36.4%, 36.6%[8], 35.6% and 35.5% [9] were reported in 2012, 2013, 2014 and 2015 respectively.

In this paper, TRIZ is employed to determine the solution's architecture system. Hence, the objectives of this study are:

i. To propose engineering solution for inconsistent water supply using TRIZ.
ii. To develop and validate the proposed solution.

II. WATER UTILITIES

Based on Water Services Industry Performance Reports, 50% of customer complaints are due to pipelines tapping, pipe bursts or breakages for the past three years [10]-[12]. The main question raised is how the water utilities can be enhanced efficiently and yet have low costs.

A. Current Problem

Reliable water supply utilities provided to the domestic users.

B. Function analysis

The function analysis is to identify the components of supersystem or subsystem in the Engineering system and also their interactions[13].The water (engineering system) is supplied to a user (product), as shown in Figure 1.

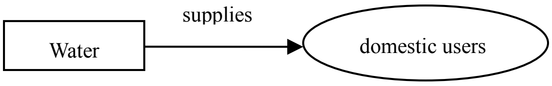

Figure 1: Water supplies for domestic users

C. Product Component Analysis

The components of the subsystem in this inconsistent water utility are (i) treatment plant, (ii) reservoir, (iii) water taps and (iv) water pipes. Meanwhile, the components of the supersystem influence the water utilities and yet are not part of the engineering system. However, those components still have interactions with the water utilities. The supersystem components are (i) flood, (ii) water resources (rain, river and groundwater) and (iii) earth surrounding. Figure 2 depicts the product component analysis of the water utilities whereby the diamond shape represents the components of the super system.

D. Cause-Effect Chain

The purpose of cause-effect chain analysis is to determine the root cause of the water interruption problem. Each cause of the water utility problem must be asked 'why' until the 'why' is unanswerable. Subsequently, every cause is assessed, either to be accepted or discarded, as a root cause of the problem. All the causes and effect chain analysis are shown in Figure 3. in this figure, the root cause of the water interruption problem is the pipeline breakage as highlighted in red. Next, a contradiction is performed by using TRIZ.

E. Engineering Contradiction

The engineering contradiction for this water utility problem is: "We want to shorten the detection time of the pipeline breakages but the cost of the water utility system increases". Referring to engineering contradiction, we conclude that the positive and negative impact as:

- Positive impact: to shorten the detection time of the pipeline breakages

- Negative impact: the cost of the water utility system increases

F. Contradiction Matrix

The positive and negative impact are categorised as improving and worsening parameters respectively and then mapped into TRIZ table which consists of 39 System Parameters. Referring to the TRIZ table, the feasible improving and worsening parameters relevant to our engineering contradiction are:

- Improving parameter: Productivity(#39)
- Worsening parameter: Ease of operation(#33), Use of energy by moving object(#19)

Therefore, the Matrix parameters become:

- Productivity versus Ease of operation (39/33)
- Productivity versus Use of energy by moving object (39/19)

Once the improving and worsening System Parameters are defined, then potential Inventive Principle solutions are obtained using cross-index the Contradiction Matrix. Referring to the Contradiction Matrix of 39/33, the Inventive Principles are listed as the following:

- Principle #1: Segmentation
- Principle #7: Nested Doll
- Principle #10: Preliminary action (Prior action – “Do it in advance”)
- Principle #28: Mechanics Substitution

Meanwhile, the Inventive Principles for Contradiction Matrix of 39/19 are :

- Principle #35: Parameter changes
- Principle #10: Preliminary action (Prior action – “Do it in advance”)
- Principle #38: Strong oxidants
- Principle #19: Periodic action

The appropriate solution from the proposed inventive principles is Principle #7. The feasible description of Principle #7 for our problem is ‘make one part pass through a cavity in the other’.

G. Potential Solution

Figure 4 illustrates the system architecture of water pipeline monitoring system used in our work. Referring to Figure 4, water flow and pressure sensors are attached to the water pipelines. The sensors data will be transferred over the Zigbee wireless and will be analysed using time domain to determine the water pipelines conditions (normal or leak).

The prototype of our pipeline system comprises the water pump, flow rate sensor, pressure meter, leak pipes and two manual valves. The function of a water pump is to generate the water flow and pressure in the pipeline system. A valve is installed in the pipeline system for controlling the pressure as well as the water flow. The water system is designed to recycle the water intake during the experiments conducted.

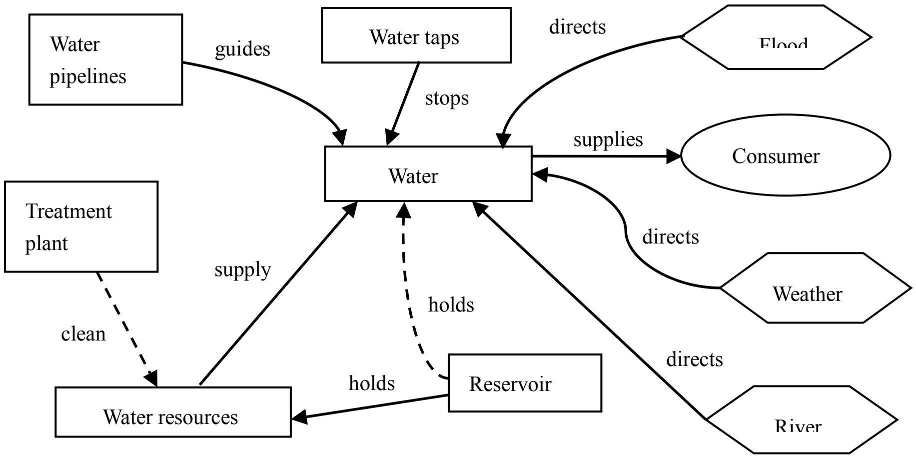

Figure 2: Engineering system for water utility

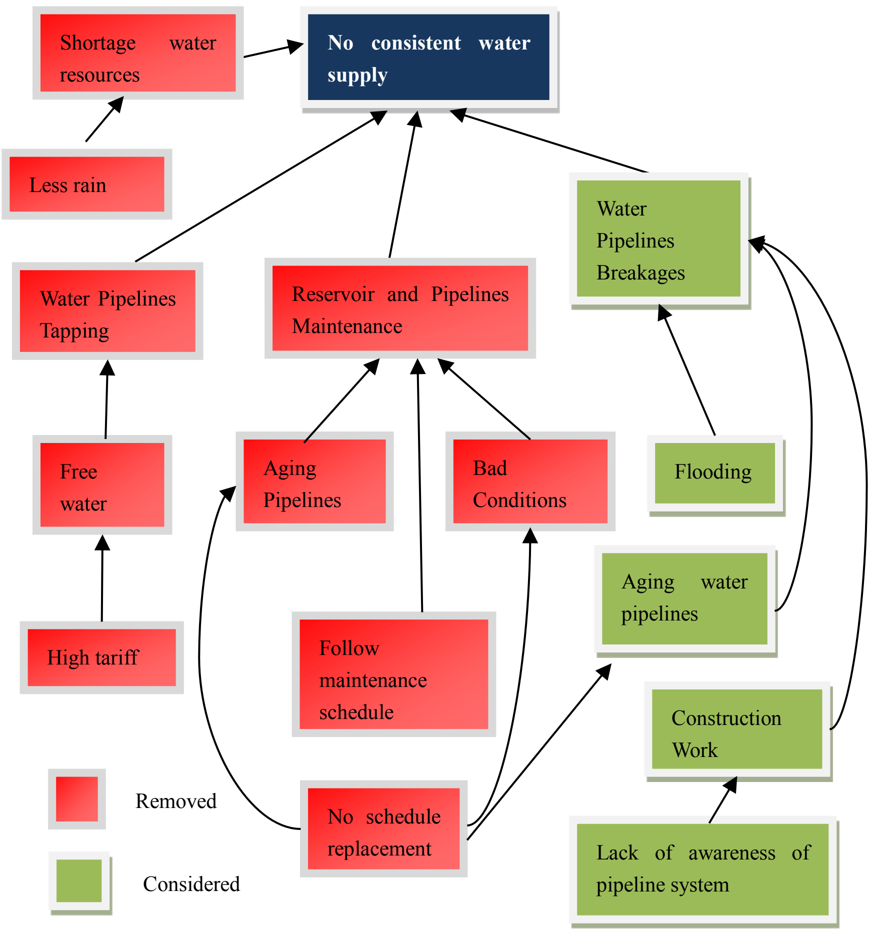

Figure 3: Cause and effect chain analysis for water utility problem

III. WATER PIPELINE TESTBED

Table 1 summarises the experimental parameters and its values that are considered in investigating the effectiveness of the proposed solution.

Table 1
Water Pipeline and Experiment Parameters

Parameter	Values
Type of Pipe	ABS
Pipe length (m)	10.0
Type of Vibration Sensor	MPU6050
The distance between pipe leaking and sensor (m)	1.5
Duration of data collection (s)	120
Time sampling (ms)	10
Water pressure (kPa)	58.867 (0.6kgf/cm^2) 78.840 (0.8kgf/cm^2) 98.067 (1.0kgf/cm^2) 117.680 (1.2 kgf/cm^2)
Size of leaking hole	No Leak 1 mm leak 3 mm leak

To evaluate a water pipeline monitoring based on vibration data, several pipe conditions are conducted: (i) no pipe leaking, (ii) pipe leaks with a size of the hole of 1 mm, and (iii) pipe leaks with a size of the hole of 3 mm. In our prototype, an inch of ABS pipe and a 10 m long of water pipeline is used.

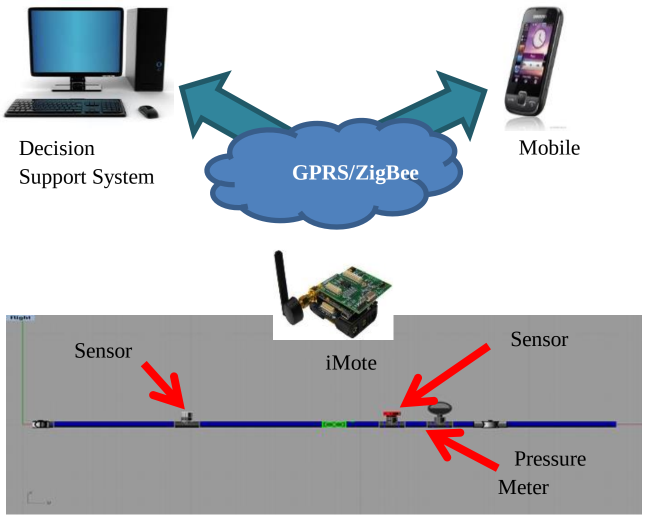

Figure 4: Proposed water pipeline monitoring and leakage system

The range between the leakage point and the MPU6050 sensor is 1.5 m. The water pressure is then varied from the valve positioned at the end of the pipeline system, and the data is collected for 120 s with a time sampling of 10 ms. The pipeline system must reach a stability mode of approximately 30s before the actual data reading is gathered from the sensor.

IV. EXPERIMENT PARAMETER

Water pipeline test bed systems [14]-[17] were developed to test methods for detecting pipeline leaks. Studies have been conducted to testbed systems in the laboratory and outdoor. Testbed systems are designed according to the parameter measurements and the type of pipeline.

A water pipeline testbed system has been designed and developed in a soil laboratory at UTM Kuala Lumpur campus. The test bed was designed using an inch diameter of ABS pipe with a length of approximately 10 meters. The testbed water pipeline has a water pump to provide water flow and pressure in the pipeline, and the end of the pipeline is connected to two ball valves. The water is circulated in the test bed system using a water pump that supports a water pressure of 0.6 to 1.6 kgf/cm2 and the water flow velocities of 10 to 25 litre/sec. The function of the valve is to control the pressure and water flow in the pipeline system. In this study, we choose an acceleration sensor called MPU6050 is attached to the ABS water pipeline system to collect vibration data. The vibration data are analysed using the signal analysis method to detect leaks and determine the sizes of the leak.

Figure 5 illustrates the system architecture of the water pipeline monitoring system used in our work. The details of the hardware design and setup of the wireless water pipeline system using MPU6050 can be found in [17].

V. RESULT AND DISCUSSION

Figure 6 demonstrates the average vibration across several pressures for the leak and no leak cases over the duration of 120s. Based on the results, the vibration technique is feasible to detect the leaking pipe for the pressure below 98 kPa. Nevertheless, the detection on the severity of the sizes of leaking is considerably dependent on the water pressure or the water flow; the higher water pressure is, the harder it is to detect small leakage (e.g. 1 mm leak at 98 kPa).

According to the Bernoulli principle, the water pressure is inversely proportional to the water flow or vice versa. Based on the magnitude of vibration, the leaking can be considerably determined when there is a fast water flow, which is at a low water pressure, as shown in Figure 6.

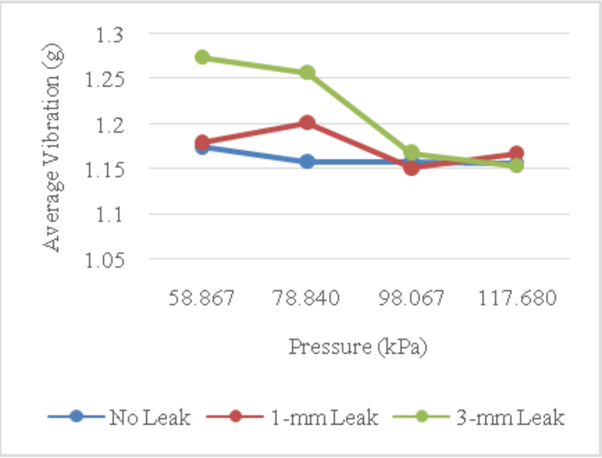

Figure 6: Average vibration for duration of 120 s under different pressure

Because the water flow causes the vibration in the pipeline, we could say that when the water slowly flows the leaking is unlikely to be identified, as can be seen for the water pressure of 117.68 kPa. As for the 3 mm leaking case, the vibration decreases when the water pressure increases. This demonstrates that the magnitude of vibration for a big pipe leaking is significantly dependent on the water pressure or the water flow. However, for the no leak case, the pressure does not substantially affect the magnitude of vibration, as we could see the vibration is quite stagnant across all the pressure in Figure 6.

One of the advantages of using vibration technique in the water pipeline leakage is it has reliable accuracy on identifying the leak from small and big holes, as demonstrated in Figure 6. Another advantage is that it is cost-efficient since only the designated device can be used to detect the leak.

VI. CONCLUSION

This paper presents the technique of applying TRIZ at every step in solving the issue of inconsistent water supply. The TRIZ tools have been found beneficial in framing the problem and setting out the direction for subsequent analyses, identifying the technical contradictions and also useful in inventing the potential solution. The testbed has been developed to evaluate the potential solution; the water pipelines are attached with several sensors, obtained from the Inventive Principle of TRIZ. A vibration technique was chosen to identify the leaking and non-leaking cases using acceleration sensors called MPU 6050. The vibration data collected was analysed according to the time domain and frequency domain to evaluate further a feasible analysis technique in solving the problem. The average vibration based on time domain can detect the pipe conditions, which are leaking and no leaking cases, for the water pressure below 98.067 kPa in the pipeline. Nevertheless, when the pressure increased, it was difficult to identify the leaking pipes. On the contrary, the FFT analysis can identify a different range of frequencies for both cases under all the tested pressure. Future work will be focused on different acceleration sensors, namely, MMA7361 and ADXL335.

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