



## KRI DESIGN AND MITIGATION STRATEGY ON WATER DISTRIBUTION OF PERUMDA AIR MINUM MAKASSAR REGIONAL IV: A Case Study

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### ABSTRACT

Municipal Waterworks Corporation (PERUMDA AIR MINUM) of Makassar city currently finds many common risks in water distribution process. The risks cause a lot of damage to the piping network system, so that the quantity of distributed water to customers is not optimal. Consequently, it is necessary to handle the risks. This study aims to determine the risks that occur in water distribution process by using Delphi method to identify potential risks. Then, House of Risk (HOR) is used at the risk analysis and evaluation stage to determine mitigation strategies and Key Risk Indicators (KRI) is designed to determine the Early Warning System (EWS). Based on the results known that there are 16 identified risk events and 24 risk agents. Furthermore, a mitigation strategy is carried out on the risk agent by using 18 preventive actions. Based on the selected risk, coded as A24 with the indicator value is Information (Field Team) has lower threshold of 5 hours and upper threshold of 8.19 hours. Water loss has lower threshold of 3,118,047 m<sup>3</sup> and upper threshold of 3,283,688 m<sup>3</sup>. A1 as Expired indicator value has lower threshold of 20 years and upper threshold of 26 years and leaking pipes replacement has lower threshold of 15 years and upper threshold of 16 years 3 months 2 weeks. Further research is expected to be able to design KRI for the risks that do not have EWS yet.

**Keywords:** Risk of water distribution, Delphi, House of Risk (HOR), Key Risk Indicators (KRI).

### Article History:

Submit 19 Agustus 2020

Received in from 2 September 2020

Acceted 25 September 2020

Avilable online 23 November

### Published By:

Fakultas Teknologi Industri  
Universitas Muslim Indonesia

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DOI : <http://dx.doi.org/10.33536/jiem.v5i2.672>



## 1. Introduction

Regional Water Utility Company (PERUMDA) is one of government business units which distributes clean water to public (Lagu., et al 2016). In its activities, PERUMDA is required to distribute clean water based on Regulation of Ministry of Health of Republic Indonesia; PERMENKES No.416/ Menkes/Per/IX/1990 about the requirements of clean water quality (Gusril, 2016). In clean water distribution system, water quality may decrease due to the growth of biofilm inside distribution pipes which can cause pathogen retention (Wang et al., 2018; Han et al., 2020). Disinfectants diffusion will be obstructed, then lead the process to proliferation that creates unpleasant tastes and odors (Waller et al., 2018). The growth of amoebae and bacteria in the distributed water can cause technical complications and diseases in humans (Yu et al., 2018; Perrin et al., 2019; Puzon., Et al 2020).

PERUMDA of Makassar city is not yet optimum in distributing clean water to its consumers, because the distributions to district Tamalanrea still need extra quantity, around 30.01 lt/second. The risk source is the availability of raw water in Lakopancing river which decrease from around  $30.90 \text{ m}^3/\text{s}$  to  $0.986 \text{ m}^3/\text{s}$  in dry season, caused by high water loss at 57.68% as the obstruction factor, as well as pipe networks system that is no longer adequate for its service areas (Lagu et al., 2016).

One of the strategies to reduce the risk impact is doing transfer risk (Toppel & Trankler, 2019). It needs to consider resources during risk analysis, and knowing the level of feasibility and needs for risk mitigation strategies (Dadsena et al., 2019). In Toppel & Trankler's research (2019); Thons & Stewart, (2019); Ceres et al., (2019) stated that risk mitigation strategy uses 3 main characteristics for strategy designing, they are the cost for implementing the strategy, the probability of risk occurrence, and risk mitigation measures which based on 3 mitigation indicators. The indicators are: (1) Cost-based risk and optimization, (2) Measuring and ensuring the significance in risk reduction, (3) Measuring and ensuring the possibility of high cost efficiency.

Previous research was conducted by Chen et al., (2019) about selection of key indicators on the risk of damage on industrial oil and gas pipelines by using Delphi and Fuzzy Analytic Hierarchy Process (FAHP) methods to prevent and reduce human, production, asset, and environmental losses. House

of Risk (HOR) is a method for managing risk proactively, where the risk event which identified as the cause (risk agent) can be managed by making order based on the dimension of the impact (Magdalena & Vannie, 2019). Shi et al., (2018) who developed Key Risk Indicators (KRI) for accident evaluation on vehicle trajectories before accidents was using 3 metrics as basic indicators : (1) risk behavior, (2) risk avoidance, and (3) risk margin. KRI was designed to evaluate risk severity. The research used hybrid method and hierarchical indicators.

This study added variables that differentiate it from previous studies. The variables used as indicators for designing Key Risk Indicators (KRI) were (1) Understanding risk behavior by doing risk identification to determine risk events and risk agents, (2) Performing risk analysis, (3) Evaluating the risks, (4) Designing risk mitigation strategies, and (5) Determining KRI.

Water distribution risk in PERUMDA consists of several problems including cloudy water, turbidity, damaged water distribution meters, and leaking pipes with the average risk level is above 30% (Purba et al., 2015). Other problems are corroded pipe, unidentified micro cracks on pipe networks, low water discharge, blockages in distribution pipes, damage in water control valves, seepage in water tanks, damage in distribution pumps, illegal connections (water theft), so that water supply to consumers is obstructed (Putra et al., 2017). PERUMDA Makassar still does not have an optimal risk management system. Thus, it is important to know the continuous risks, means that monitoring the occurred risks is necessary.

This research was conducted to determine the risks that occur in water distribution by using Delphi and HOR phase 1 methods, to propose mitigation strategies for reducing the impact of water distribution risk by using HOR phase 2, and to design KRI which can be used as the initial sensor for risk treatment of water distribution in Region IV Ratulangi of PERUMDA Makassar. By doing this research, it is possible to picture the risks in water distribution and to evaluate the efforts.

## 2. Research Method

This research was conducted at PERUMDA Makassar Region IV, South Sulawesi, Indonesia. The focus of this research was to identify risks in water distribution by using Delphi, then to measure, evaluate, and design the mitigation strategies by

using House of Risk (HOR) approach, as well as to design Key Risk Indicators (KRI).

## 2.1. Type of Data

### 2.1.1. Primary Data

The primary data in this research were obtained directly from sources or experts through observation, interviews, questionnaires, brainstorming, and focus group discussions (FGD) with a team led by Head Division of Distribution, Section Chief of Maintenance, Head Division of Engineering Planning, and Section Chief of Planning & Supervision of PERUMDA Makassar regarding risks potential in water distribution process, severity evaluation (risk event), occurrence (risk agent), correlation between risk events and risk agents, determining and weighting the difficulty level of mitigation strategies, determining Key Risk Indicators (KRI) matrix, and weighting The Gap Assesment Tool.

### 2.1.2. Secondary Data

Secondary data were obtained not directly from the company, but through other sources, such as company documentation in form of company photos, journals from 2000 to 2020, books, so on. The secondary data supported primary data.

## 2.2. Methods of Data Processing and Analysis

Data processing in this study used Delphi method to identify potential risks in water distribution with the indicators were consisted of piping, supply / storage, facilities, planning, and monitoring. Furthermore, statistical data processing was carried out, which was determining the average value (mean), middle value (median), standard deviation, and Inter-Quartile Range (IQR).

The next step was using House of Risk (HOR) phase 1 to weight the severity of risk event and the occurrence of risk agent as well as the correlation evaluation from both to obtain Aggregate Risk Priority (ARP). HOR phase 2 determined the mitigation strategy, as well as the evaluation of difficulty level in each treatment obtained from the results of focus group discussions (FGD) with experts.

The last step in determining key risk indicators (KRI) was by performing rootcause analysis to determine matrix and weighting indicators in the gap assessment tool, so that further analysis can be carried out to determine early warning system (EWS).

The indicators that used to identify potential risks in water distribution process were as follows:

**Table 1. Indicator and Risk Potential of Water Distribution**

Indicators	Risk Potential
Piping	Corrosion in distributing pipe
	Damage in water distribution pipe to customer's house
	Underground installed pipes are dented and difficult to identify
	Micro cracks in the distribution pipe network which difficult to identify
	Depletion of wall of distribution pipe
	The water discharge obtained by the customer is low
	Clogs in distribution pipe
	Damage in water control valve
Supplies/Storage	Accidental damage of a single pipe (pipe burst)
	Leakage in pipe connection
Facilities	Water discharge in the reservoir decreases
	Damage in distribution pump
Planning & Supervising	Damage in water distribution meter
	Premature aging of water distribution equipment
Planning & Supervising	The occurrence of illegal connections (water theft)
	Water loss in distribution process

## 3. Result and Discussion

### 3.1. Risk Identification

The identification of risk event in water distribution used HOR phase 1. Based on Delphi

consensus, 16 risk events were obtained. Table 2 showed the result of risk identification.

**Table 2. List of Risk Event and Severity Evaluation**

No	Risk Event	Code	Severity
1	Corrosion on distribution pipe	E1	6
2	Damage in water distribution pipe to customer's house	E2	8
3	Underground installed pipes are dented and difficult to identify	E3	6
4	Micro cracks in the distribution pipe network which difficult to identify	E4	6
5	Depletion of wall of distribution pipe	E5	5
6	The water discharge obtained by the customer is low	E6	9
7	Clogs in distribution pipe	E7	7
8	Damage in water control valve	E8	6
9	Accidental damage of a single pipe (pipe burst)	E9	9
10	Leakage in pipe connection	E10	6
11	Water discharge in the reservoir decreases	E11	5
12	Damage in distribution pump	E12	7
13	Damage in water distribution meter	E13	6
14	Premature aging of water distribution equipment	E14	5
15	The occurrence of illegal connections (water theft)	E15	10
16	Water loss in distribution process	E16	8

Table 2 above shows the weighted results of severity value of each risk event. After perceiving the category of each risk, the next step determined

the source of risk (risk agent). The following table 3 is a list of risk sources for each risk event and weighting of occurrence value.

**Table 3. List of Risk Agent and Occurrence Weighting**

No	Risk Agent	Code	Occurrence
1	The technical life of pipes passed its usage limit	A1	5
2	Drainage excavation	A2	6
3	Excavation of cable installation from external parties	A3	5
4	Load vibration from the surface	A4	5
5	Lackness in automatic pipe monitoring system	A5	8
6	Does not have early warning system	A6	7
7	Erosion Corrosion (Erosion of pipe walls)	A7	5
8	Numbers of damaged water control valves	A8	4
9	Damage in water treatment plant	A9	4
10	Lack of water pressure	A10	6
11	Considerable amount of material carried away when heavy flow	A11	4
12	Clogged by tree roots	A12	4
13	The valves passed its useful limit	A13	9
14	High pressure from the outside part	A14	4
15	Pipes quality does not meet the standard	A15	3
16	Pipelines that doesn't set under supervision	A16	4
17	Leaks or seepage on reservoir	A17	5
18	Unstable electrical voltage from PLN (National Electricity Company)	A18	4
19	Pumps exceeded its service limit	A19	2
20	The water meter is too old	A20	9
21	Lackness in equipment maintenance	A21	5
22	Lack of supervision from internal company parties	A22	10
23	In-house pipe installations	A23	4
24	Undetected leakage	A24	8

From the table above known that there were 24 risk agents with the occurrence value of each risk agent. The occurrence values and the severity values

of risk event became the input for house of risk phase 1. Furthermore, it also used the correlation values between risk event and risk agent.

### 3.2. Risk Analysis

Risk identification was the last step of HOR phase 1. Based on the measurement in table of HOR phase 1, severity value of risk event, occurrence value of risk agent, and correlation between risk event and risk agent were shown. In addition, Aggregate Risk Potential (ARP) values and the ranking of risk agents which being prioritized for risk mitigation were obtained. From the identification results, there were 16 risk events and 24 risk agents. The calculations of ARP values were carried out to determine the prioritized risk agents to be mitigated. The results of ARP formed in pareto chart with the principle ratio was 80:20.

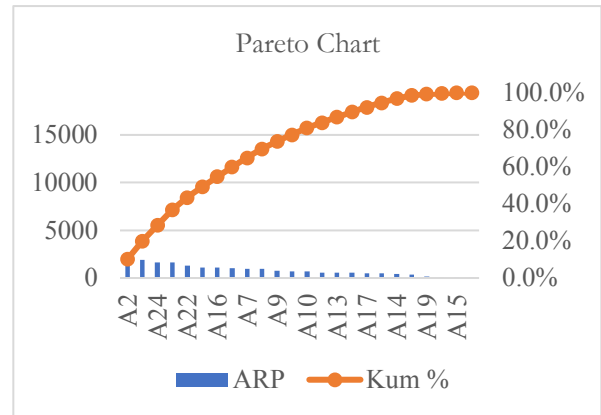


Figure 1. Pareto Chart of Risk Agent

### 3.3. Risk Evaluation

Based on obtained ARP value from the measurement on HOR phase 1, the next step was determining dominant risk agent with pareto chart. The measurement was to determine the source of dominant risk. Pareto chart was made by using cumulative percentage of each ARP values of risk agent. Picture 1 below shows the pareto chart of risk agents.

The basis of risk evaluation in HOR phase 1 was a pareto diagram based on ARP value of risk agents which were prioritized for treatment. 80:20 principle ratio was used in this risk evaluation. 77.3% risk agents were taken to design handling strategy which was expected to help the improvement of other 22.7% risk agents. There were 12 dominant risk agents out of a total of 24 risk agents in water distribution activities. The following table 4 contains the lists of dominant risk sources.

Table 4. Dominant Risk Agent Before Treatment

No	Code	Risk Agent	ARP	Severity	Occurrence
1	A2	Drainage excavation	1980	9	6
2	A5	Lackness in automatic pipe monitoring system	1904	7	8
3	A24	Undetected leakage	1656	9	8
4	A12	Clogged by tree roots	1608	8	4
5	A22	Lack of supervision from internal company parties	1300	8	10
6	A3	Excavation of cable installation from external parties	1110	6	5
7	A16	Pipelines that doesn't set under supervision	1068	7	4
8	A23	In-house pipe installations	1004	7	4
9	A7	Erosion Corrosion (Erosion of pipe walls)	975	7	5
10	A1	The technical life of pipes passed its usage limit	960	9	5
11	A9	Damage in water treatment plant	780	7	4
12	A6	Does not have early warning system	700	6	7

After knowing the list of prioritized risk sources, a dominant risk mapping was carried out with the aim of seeing risk conditions before

mitigation. The mapping aimed to see risk conditions before mitigation. The position of dominant risk source shown in Figure 2 below:

Probability (Occurance)	Very High	Green	Yellow	Red	A22	Red
	High	Green	Yellow	A6	A5	A24
	Medium	Green	Green	Yellow		A2
	Low	Green	Green	A3	A7	A1
	Very Low	Green	Green	Green	A12, A16, A23, A9	Red
	Very Low	Low	Medium	High	Very High	
	Impact (Severity)					

**Figure 3. Risk Map Before Mitigation**

In Figure 3 above, there are 3 levels of risk. Red means high risk, yellow is medium risk, and green is low risk. The map shows that the agents with codes A24, A2, A1, A22, A5, A7, and A6 are considered as high so that they needed to be handled as soon as possible. Meanwhile, risk agents with codes A12, A16, A23, A9, and A3 are medium, thus necessary to carry out routine handling and effective control. From this map can be concluded that to design a mitigation strategy in PERUMDA Makassar is necessary, so that water distribution is properly done.

### 3.4. Designing Mitigation Strategy

There are several prioritized mitigation that need to be carried out to reduce the impact of risk sources. The following is the sequences of mitigation priority based on calculations using the house of risk (HOR) table phase 2, in table 5:

**Table 5. Prioritas Strategi Mitigasi Risk Agent**

No	Preventive Action	Code
1	Direct field supervision	PA2
2	Provision of Leak Noise Correlator for active search of leakage	PA3
3	Periodic pipelines inspection	PA5
4	Increasing internal supervision of the company	PA8
5	Implementing fines in accordance with company regulations	PA10
6	Supervision toward PERUMDA external project activities	PA12
7	Perform calibration on customer's water meter	PA13
8	Install valves in each distributary pipe to detect leakage	PA4
9	Replacing potentially damaged pipes	PA6
10	Rehabilitation of new pipes to replace improper pipes	PA15

No	Preventive Action	Code
11	External parties are required to coordinate with PERUMDA before operation in the piping area	PA11
12	Discipline in carrying out routine maintenance	PA17
13	Regular monitoring of corrosion potential	PA14
14	Coordinating with the drainage improvement company	PA1
15	Taking a decisive action by cutting illegal connections	PA9
16	Implementing effective pipeline supervision scheduling	PA7
17	Combing the pipe networks when water pressure is stable (at night)	PA18
18	Creating a database of pipe age for early warning system	PA16

After prioritizing the treatment based on the effectiveness level of implementation, the experts then performed severity and occurrence assessment when the given handling strategy was implemented. The following figure 4 is the risk maps after mitigation strategy being carried out:

Probability (Occurance)	Very High	Green	Yellow	Red	Red	Red
	High	Green	A5, A6	Red	Red	Red
	Medium	Green	Green	A22	Red	Red
	Low	Green	Green	A2, A24	Red	Red
	Very Low	Green	A23, A3	A16, A9, A12	A7, A1	Red
	Very Low	Low	Medium	High	Very High	
	Impact (Severity)					

**Figure 3. Risk Map After Mitigation**

Figure 4 above shows map risk after designing treatment priorities. Risk agents with codes A24, A2, A1, A22, A5, A7, and A6 were initially in the red area which indicated high risk before mitigation implementation. After mitigation, the codes shifted down to the yellow area which indicated medium category, so they still need to be managed regularly and put under effective control, as well as implementing the designed treatment strategies. Meanwhile, risk agents with codes A12, A16, A23, A9, and A3 which in the yellow area before mitigation were shifted down to the green area, indicated that the risks already in the low

category so that routine monitoring and normal control were sufficient.

### 3.5. Determining Key Risk Indicators

This was last stage of designing key risk indicators, which the selected risks based on expert agreement were : (1) Undetected leakage (A24), and (2) Technical life of pipes had passed its usage limit (A1).

#### 3.5.1. Identification of Indicator Matrix

This was the identification process of root cause analysis matrix upon the risk, referred to the company's vision and mission. The results of determining indikator matrix on the risk of undetected leakage (A24) were : (1) Customer complaints, (2) Coordination of external parties, (3) Informations (field team), (4) Low water discharge, (5) Water quality (smell), (6) Water loss. Furthermore, on A1 risk (technical life of pipes passed its usage limit) were : (1) Road load pressure, (2) Expired (3) Pipe replacement time, (4) Pipe repair time, (5) Data of leaking pipe replacement, (6) Customer meter data.

#### 3.5.2. Determination of The Gap Assessment Tool

After determining indikator matrix on KRI, the next step was evaluating the feasibility and effectivity of each indikator matrix based on the dimension of Gap Assessment, which were : Frequency, (2) Trigger Level, (3) Evaluation criteria, (4) Leading/lagging, (5) Ownership, (6) Historical data, and (7) Data Accuracy. From the determination results were obtained 2 indikator matrix on A24 risk : (1) Information (field team) with value of 4.7, and (2) Water loss with value of 4.6. Then A1 : (1) Expired with value of 4.6, and (2) Leaking pipe replacement with value of 4.4, which then used as the basis to determine the threshold.

#### 3.5.3. Determination of KRI Threshold

Based on selected indikator matrix from risks A24 and A1, the next step was determining the threshold of KRI. Table 6 is the result of determining the threshold :

**Table 6. Threshold Key Risk Indicators**

Key Risk Indicator	Parameter		Measuring Unit
	Lower Threshold	Upper Threshold	
Information (Field Team)	5	8, 19	Hour
Water Loss	3.118.047	3.283.688	M <sup>3</sup>
Expired Data of Leaking Pipe	20	26	Year
Replacement	15	16,32	Year

Based on the results of determining KRI Threshold in table 6 were discovered that information indicator (Field Team) had lower threshold of 5 hours and an upper threshold of 8.19 hours. Water loss indicator had lower threshold of 3,118,047 m<sup>3</sup> and an upper threshold of 3,283,688 m<sup>3</sup>. By the early warning at risk indicator A24, anticipation can be done to reduce the impact of the risk that occurs if the handling is still within control. Furthermore, Expired indicator had lower threshold of 20 years and upper threshold of 26 years of distribution pipes use at normal times, then, the indicator for leaking pipe replacement had lower threshold of 15 years and upper threshold of 16 years 3 months 2 weeks applied on distribution pipes replacement. The using of pipes which not reaching its usage limit mainly caused by beyond control incident.

## 4. Conclusions and Suggestions

### 4.1. Conclusion

From the evaluation result of risk determination of water distribution in PERUMDA Makassar Region IV can be concluded that there are 16 identified risk events and 24 risk agents. Furthermore, mitigation strategy was carried out upon risk agent by using 18 preventive actions. The first selected risk was A24 with the value of Information indicator (Field Team) had lower threshold of 5 hours and upper threshold of 8.19 hours. Water loss had lower threshold of 3,118,047 m<sup>3</sup> and upper threshold of 3,283,688 m<sup>3</sup>. The second was A1 with Expired as the indicator value whose lower threshold is 20 years and upper threshold of 26 years, and leaking pipe replacement with lower threshold of 15 years and upper threshold of 16 years 3 months 2 weeks.

## 4.2. Suggestions

Regarding the result of this research, the first suggestions is for PERUMDA Makassar Region IV Ratulangi to implement the prioritized mitigation strategy to reduce risk impact. Next is for further research to design key risk indicators (KRI) upon risk that is not having EWS yet.

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