Statistical Sampling Strategy for Pipeline CCTV Inspection

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Abstract

Pipeline condition data collection and assessment is the first step for the strategic infrastructure asset management and planning. However, the data collection and assessment process is so expensive and time consuming process that the asset management often fails even before it starts. Many municipalities perform periodic CCTV inspections repairing the encountered problem areas. However, because of the limited budget, only a few amount of pipelines are inspected hoping not too much problematic areas to be found that require immediate repair. In this research, statistical sampling methodology has been applied in order to strategically choose the areas for the inspection and estimation of the overall condition of the pipelines minimizing the complete CCTV inspection to reduce the inspection cost. It improves the overall condition of the area as well as accurately estimates the overall condition that provides the fundamental basis for the strategic infrastructure asset management. Acceptance sampling method is used which is widely used in quality control of manufacturing industry. First, pipelines are categorized based on ages and materials and any other categories that are believed to be similar conditions. Then randomly selected pipelines are inspected. The amount of the selection is determined by the municipality's budget. Once the sampling is performed, the overall condition is same as average of the samples. However, by repairing the found problems during sample inspection, not only the average condition of the samples increases but also the overall condition of the area improves. In addition, most importantly, the overall condition is statistically estimated for the categorized area. The Average Outgoing Quality (AOQ) is the final average condition of the pipelines that is improved and statistically validated estimation. This research presents the strategic sampling plan for pipeline CCTV inspection with limited budget and maximize the overall conditions and the most accurate condition estimation with probability confidence interval.

Introduction

Municipalities and local communities started aware the importance of the maintenance of the underground infrastructures which have been often forgotten until they collapse and impact the community's health and safety. In order to improve the levels of service quality and extends the service life of the infrastructure, Infrastructure Asset Management has been used by managers of the facilities (Han et al 2014).

The first step of the asset management is understanding the current condition of assets by condition assessment. In case of underground pipeline infrastructures, condition assessment is performed by CCTV video inspection along with alternative methods such as smoke

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testing, and dye water testing to detect leaks. Once the current condition is identified, then repair/replacement/rehabilitation plan is made. Instead of delivering high quality defect free infrastructures, non-asset alternatives can also be reviewed such as improving the customer service and providing warranty services. Often this method is more effective for those things that do not result immediate and critical impact to the health and safety. (NAMS 2015)

In order to understand the current condition of assets, in case of underground pipeline asset management, the most common method of inspection is video recording of pipes with remote controlled CCTV camera (Fig. 1 and Fig. 2). Preventive periodic inspection is performed in order to prevent failure that causes environmental hazards before it happens. For example, maintenance authority may have the policy such as "sanitary sewer pipelines would be inspected every 10 years." However, in reality, this is usually not done as planed because of the budget restriction and lack of interests in the community until the serious problem occurs and impacts the health and safety of the community.

Figure 1. CCTV for Pipe Inspection

Figure 2. Sanitary Sewer Pipe CCTV picture

Alternatively, it is possible to save cost of maintenance by inspecting the pipelines by sampling instead of full inspection. Because the inspection cost is the major capital expenditure of the pipeline asset management, sampling would relieve the barrier of budget limitation and provide motivations to start the asset management process.

This paper presents the sampling method for the pipeline inspection as a part of the pipeline asset management. The statistically proven sampling method describes the designing of the sampling strategy. The paper presents the most appropriate number of samples according to the cost of inspection and the probability of the risk of incorrectly estimating the asset condition. Sensitivity analysis was performed to understand impact of the sampling accuracy depending on the sampling policy.

A case study was performed with the data collected in Jincheon, South Korea. Sanitary and storm sewer pipes, water treatment facility were built by the Public Private Partnership (PPP) and the facility is under operation by Kolon Water & Energy, Inc. During the 30-year concession period, the maintenance company has to maintain certain level of performance and condition of the facility. This private company has a strong motivation to save cost maintaining required service level. Failing to meet the required level of service would result penalty and or loss of business.

Pipeline CCTV Inspection, I/I, and Condition Assessment

Sanitary sewer pipeline inspection is the first step for the planning of the pipeline asset management because the understanding the current condition is the first thing to do. The problem is that the inspection and assessment is cost intensive process and time consuming. Many municipalities and utility managers often abandon the periodic inspection until the catastrophic failure occurs. However, they do not have much choice due to the budget and time constraints.

The CCTV inspection of the sanitary pipelines are often more than 60~70% of the pipeline system management cost. This does not mean that condition assessment is more important than actual repair or replacement. But without accurate condition assessment, repair or replacement cannot be done correctly.

There are many methods of condition assessment: CCTV, smoke test, dye water test, Ground Penetrating Radar (GPR), etc. Inspection methods are eventually for the detection of Infiltration and Inflow (I/I). CCTV inspection shows the condition of the pipe visually such as cracked pipe and open joints that cause I/I, which in turn causes dilution in sanitary sewers that increases the volumes of sewer water and decreases the efficiency of sewer treatment. It is difficult to identify the exact location of the I/I. However, it is possible to estimate I/I by monitoring and analyzing the flow quantity on day/night, rain/dry weather, summer/winter conditions. The differences between the flow quantities during dry season and rainy season could be the indicator of the I/I. In the same way, sanitary water volume difference between day time and night time that most people do not use water, would tell the amount of I/I. For example, night time, during dry season, the flow volume is almost zero, while the amount of the flow in the same time during rainy weather can be considered I/I because rain water gets into the sanitary pipes and increase the volume. This method of I/I assessment requires flowmeters that also require cost and time to manage. Despite all these, the flow quantity

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differences tell only the indirect measure of I/I. CCTV inspection along with the GIS map data is the required to accurately identify the problem areas that need to be repaired (Fig. 3). As previously mentioned, CCTV inspection is often neglected for its high cost and time so the maintenance authority often relies on the indirect assessment which is less accurately identify the cause of the problem.

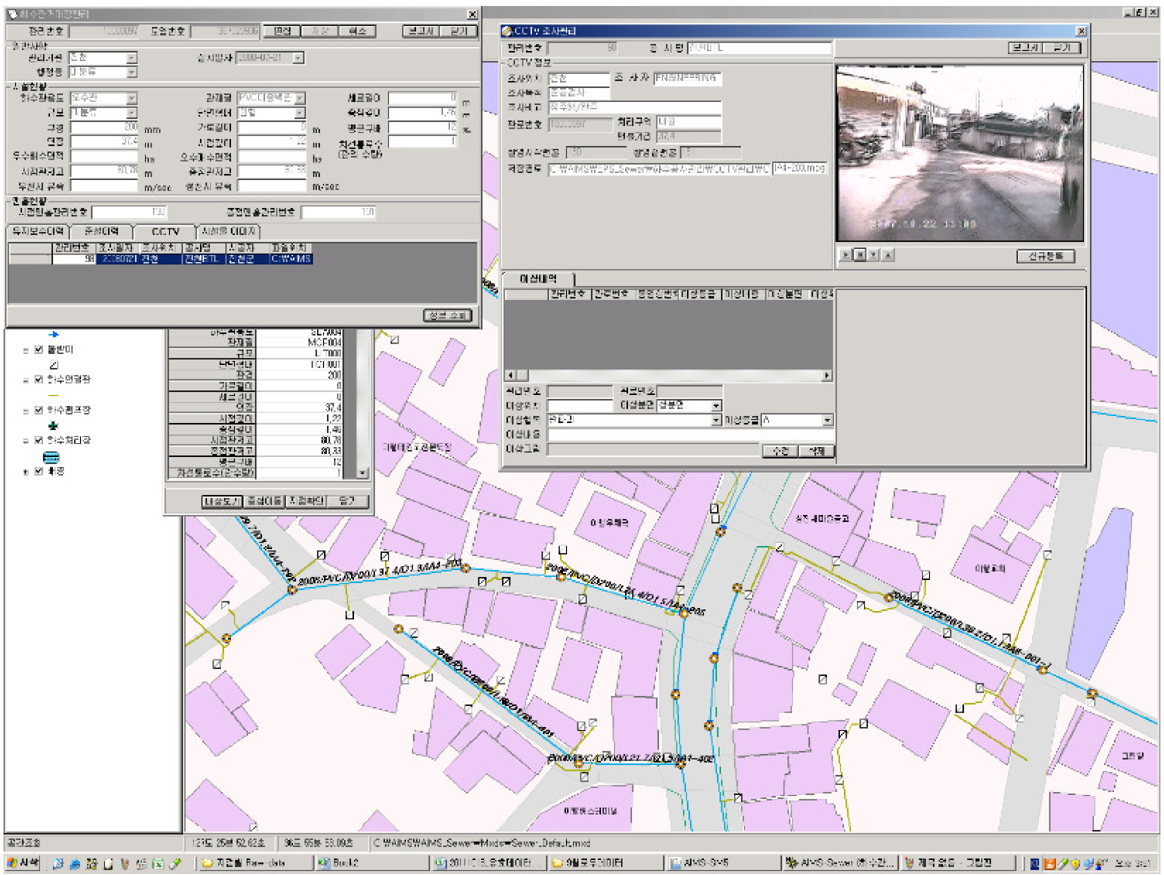

Figure 3. Sewer pipeline management system (Kolon Water & Energy 2011)

Sampling Inspection

The authors chose the Public-Private-Partnership project of the sanitary sewer pipeline and water treatment system. As the contract condition, private company that maintains the sewer water system continuously performs the CCTV inspection. The yearly inspection will cover the whole pipelines systems in 10-year period. This means that the maintenance company performs inspection for the certain areas yearly and in 10 years, there will be no pipe left not-inspected. In this way, the maintenance company is relieved for the high inspection cost in a short period time.

When defect areas are found during the periodic inspection, the maintenance company always fixes and repairs defect areas immediately. Thus, the inspected areas always do not

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have any identified defect. This inspection and maintenance method sounds reasonable however it is not very cost effective because the pipeline asset manager has to inspect 100% of the asset in the end of 10 year period.

The private maintenance company categorizes pipe assets by the ages and locations. However there is no specific rule to choose which assets are inspected first and which are inspected later. In reality routine work plan is the governing factor choosing the pipes to inspect. In fact, the order of inspection is not really an important issue because all the pipe assets are inspected and repaired and all will be perfect condition in 10 years assuming that the repaired parts maintain in good condition for at least 10 years. But this is an over performing of asset management and there are large room to save cost without sacrificing the condition level of the assets.

There are many sampling methods developed by statisticians and quality management experts however Acceptance Sampling method is adopted in this paper for its simplicity and meeting the maintenance policy that mandates the maintenance company to perform periodic condition inspections for all the pipelines and identified pipe sections to be repaired immediately.

Acceptance sampling follows either binomial distribution or hypergeometric distribution. For example, if N number of pipe sections need to be inspected, n number of samples are taken and if the defective sections are found less than the criteria, c, then all the pipes in the area are accepted. When n/N is small, i.e., N is very large or infinite, then hypergeometric distribution can be used. When N is limited and n/N is not large enough, binomial distribution can be applied.

Pipeline inspection sampling begins with the categorization of the similar groups of pipes, random sampling, repairing the detected defects, and improving the average outgoing quality. The process can be shown as Figure 2 (Chae et al 2013).

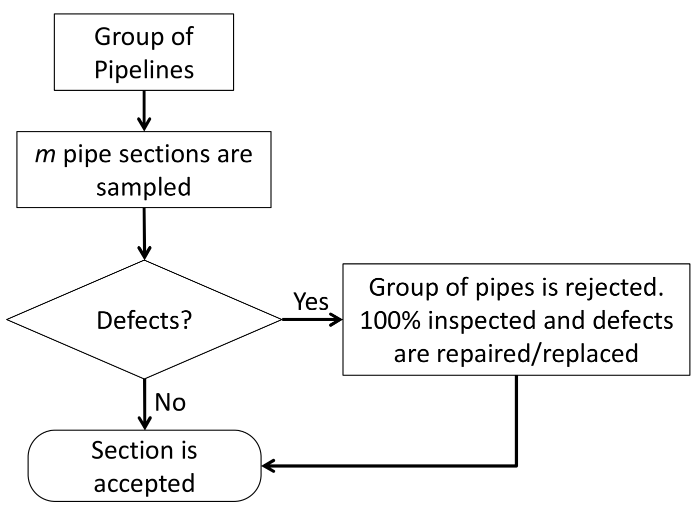

Figure 4. Acceptance Sampling Process

Outgoing Quality of the Inspected Area

According to Montgomery (2009) acceptance sampling is useful when

- When testing is destructive
- When the cost of 100% inspection is extremely high
- When 100% inspection is not technologically feasible or would require so much calendar time that production scheduling would be seriously impacted.
- When there are many items to be inspected and the inspection error rate is sufficiently high that 100% inspection might cause a higher percentage of defective units to be passed than would occur with the use of a sampling plan.
- When the vendor has an excellent quality history, and some reduction in inspection from 100% is desired, but the vendor's process capability is sufficiently low as to make no inspection an unsatisfactory alternative.
- When there are potentially serious product liability risks, and although the vendor's process is satisfactory, a program for continuously monitoring the product is necessary.

Pipe asset condition assessment can be categorized as high inspection cost and time consuming process. In addition, the inspection error rate is also high, i.e., often important defects are not found by the CCTV inspection. To make the situation worse, CCTV inspection often requires confined work space activities and this results safety hazard issue. There are many reasons to minimize the inspection activities and sampling method, if it provides certain level of accuracy for condition assessment, is the preferable option.

Case Study - Background

The data were collected in the City of Jin-Cheon, South Korea. In this case study, authors utilized the data from the sewer system development / rehab /repair project. The annual maintenance report includes engineering aspects as well as the customer relationship aspects along with the finance and asset condition reports.

The sanitary and storm pipelines and water treatment systems were developed by Public-Private-Partnership. The scope of project includes the newly installing pipes and rehabilitation of the existing old pipes. Sanitary and storm sewer pipes are total 63.5 *km* long in 4 basins (Table 1). Thus the maintenance company allocate the budget for periodic inspection for about 6.3 *km* of the pipes every year. Because it is a part of the PPP contract, public part and the private company have agreed to inspect 6 *km* of pipe every year at the cost of the private party. It is expected that there could be possible cost saving methods by reducing the amount of the pipe inspection because majority of the sanitary pipe and half of storm pipes are newly constructed and if they are properly installed the chance of defect would be very low during the 30 year concession period.

Table 1. Sewer pipe assets (unit: *meters*)

Basin		Baek-Gok	Byuk-Am	Gyo-Sung	Cho-Pyong	**Sum**
Sanitary Sewer Pipe	New	7,451	15,998	18,498	10,397	52,344
	Rehabilitated			538		538
	Total	7,451	15,998	19,036	10,397	**52,882**
Storm Sewer Pipe	New	654	2,597	748	990	4,989
	Rehabilitated	125	1,141	4,318		5,584
	Total	779	3,738	5,066	990	**10,573**
Total						**63,455**

Table 2 shows the inspected sanitary pipes during 3/4 of year 2011 which is the 1/4 of the yearly inspection amount and 1/40 of the total length of the pipelines. The lengths of the inspection section is not shown in the quarterly report however, it can be assumed that each section is about average 49.6 *meters* which is the exactly the same length for 1/4 of yearly inspection length. Section BG1942-001 to 003 have some sediments that needs to be cleaned but they are not defects of the pipeline system. No repairing job was performed but cleaning. If the sampling method had been used for this area, the maintenance company would have saved cost.

Table 2. CCTV Inspection result for 3rd quarter report in the year 2011 (Total 32 sections, 1586 *m*)

Area	Basin	Pipe Section ID	CCTV Inspection Result
Jin-Cheon	Gyo-Sung	GS1000-007	No Defect found
		GS1600-105	No Defect found
		GS1700-003	No Defect found
		GS2000-017	No Defect found
		GS2000-022	No Defect found
		GS2000-027	No Defect found
		GS2000-040	No Defect found
		GS2000-044	No Defect found
		GS2004-002	No Defect found
		GS2009-003	No Defect found
		GS2009-101	No Defect found
		GS2021-104	No Defect found
		GS2060-005	No Defect found
		GS2100-019	No Defect found
		GS2143-101	No Defect found
		GS2400-009	No Defect found
		GS2400-018	No Defect found
		GS2440-004	No Defect found
		GS2710-001	No Defect found

		BG1310-002	No Defect found
		BG1800-005	No Defect found
		BG1800-007	No Defect found
		BG1810-101	No Defect found
		BG1900-009	No Defect found
		BG1930-006	No Defect found
	Baek-Gok	BG1930-015	No Defect found
		BG1942-001	some sediment
		BG1942-002	some sediment
		BG1942-003	some sediment
		BG2000-009	No Defect found
		BG2000-102	No Defect found
		BG2100-009	No Defect found

Figure 5 to 9 show the manholes and surrounding areas for the inspection. The inspection is part of the maintenance activity and the pictures were taken to show the condition of the pipes. The inspection results have been input to the maintenance system separately.

Figure 5. Section GS2000-017

Figure 6. Section GS2004-002

Figure 7. Section GS2000-027

Figure 8. Section BG1941-001

Figure 9. Section BG2000-102

Sampling and Probability of Defects

Suppose the probability of defects of the pipe is p and the probability of acceptable is p_a, the probability of acceptance can be defined as

$$p_a = p\{d \leq c\} = \sum_{d=0}^{c} \binom{n}{d} p^d (1 - p^d) \quad \text{(Eq. 1)}$$

where d is the number of defects and c is the maximum number of defects to accept the lot.

By differing the values for p with given n and c, the following calculation result can be obtained by assuming $n = 13$ (Table 3). The curve that shows the p and p_a is called Operational Characteristics (OC) Curve (Figure 10). The reason for assuming $n=13$ is because it is about 1/10 of the yearly amount of inspection which is about 128 sections of pipes. This means that the asset manager selected 1/10 of the pipes that need to be inspected. Figure 11 shows the OC-Curve when $n = 26$.

For example, according to the calculated table, when probability of the defect is 0.1000 and when 1 or 0 defects are found in 13 samples, the probability of acceptance (i.e., 1 or 0 defects is found) is 0.6213. When $c=0$ policy is used, i.e., if any defect is found the whole lot is rejected, the probability of acceptable becomes very low when the fraction of defect, p, become large.

It would be practical to set c=1 or c=2 depending on the tolerance level of the fraction defective of the assets. Depending on the maintenance company's policy, the value for c can be set differently. However $c=0$ is not a realistic policy because the rate of acceptance is very low and it would lose the benefits of sample inspection. When the rate of acceptance is very low and the most lots are subject to the full inspection, the acceptance sampling method will not be different from the full inspection and it will end up to cost more than simple full inspection method. Thus, realistically, when acceptance sampling method is used, it usually has $c>0$ policy. The purpose of the acceptance sampling method is to save inspection cost and time. If the products require high quality, have direct impacts on health and safety, and defects are not acceptable, the sampling method is not a good approach.

Table 3. Operation Characteristic when n= 13

p	*Pa (c=0)*	*Pa (c=1)*	*Pa (c=2)*
0	0	0	0
0.0050	0.9369	0.9981	1.0000
0.0100	0.8775	0.9928	0.9997
0.0150	0.8216	0.9843	0.9991
0.0200	0.7690	0.9730	0.9980
0.0250	0.7195	0.9594	0.9963
0.0300	0.6730	0.9436	0.9938
0.0350	0.6293	0.9260	0.9906
0.0400	0.5882	0.9068	0.9865
0.0450	0.5496	0.8863	0.9814
0.0500	0.5133	0.8646	0.9755
0.0550	0.4793	0.8420	0.9686
0.0600	0.4474	0.8186	0.9608
0.0650	0.4174	0.7946	0.9520
0.0700	0.3893	0.7702	0.9422
0.0750	0.3629	0.7455	0.9316
0.0800	0.3383	0.7206	0.9201
0.0850	0.3151	0.6957	0.9078

0.0900	0.2935	0.6707	0.8946
0.0950	0.2732	0.6459	0.8807
0.1000	0.2542	0.6213	0.8661
0.1050	0.2364	0.5970	0.8508
0.1100	0.2198	0.5730	0.8349
0.1150	0.2043	0.5494	0.8185
0.1200	0.1898	0.5262	0.8015
0.1250	0.1762	0.5035	0.7841
0.1300	0.1636	0.4814	0.7663
0.1350	0.1518	0.4597	0.7481
0.1400	0.1408	0.4386	0.7296
0.1450	0.1305	0.4182	0.7109
0.1500	0.1209	0.3983	0.6920
0.1550	0.1120	0.3790	0.6729
0.1600	0.1037	0.3604	0.6537
0.1650	0.0959	0.3423	0.6345
0.1700	0.0887	0.3249	0.6152
0.1750	0.0820	0.3082	0.5960
0.1800	0.0758	0.2920	0.5769
0.1850	0.0700	0.2765	0.5578
0.1900	0.0646	0.2616	0.5389
0.1950	0.0596	0.2473	0.5202
0.2000	0.0550	0.2336	0.5017

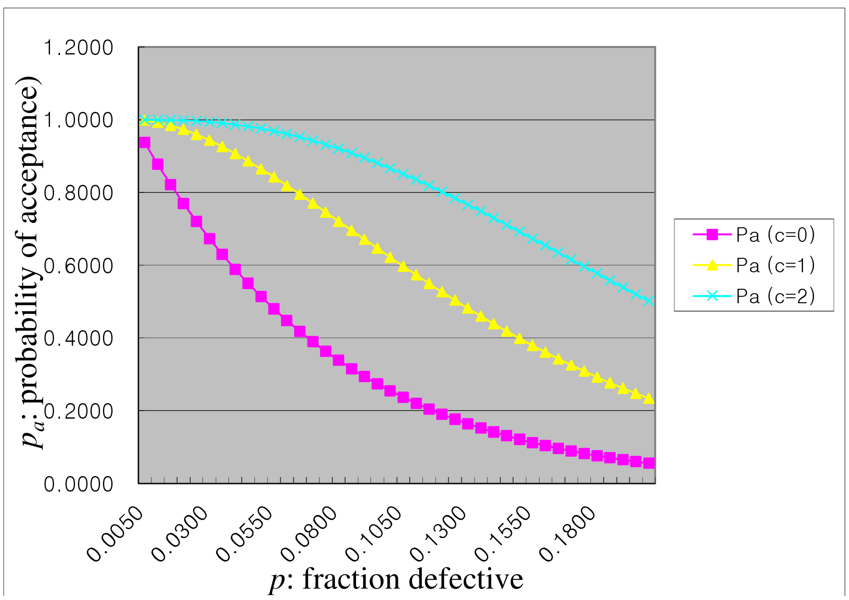

Figure 10. Operation Characteristics Curve ($n=13$)

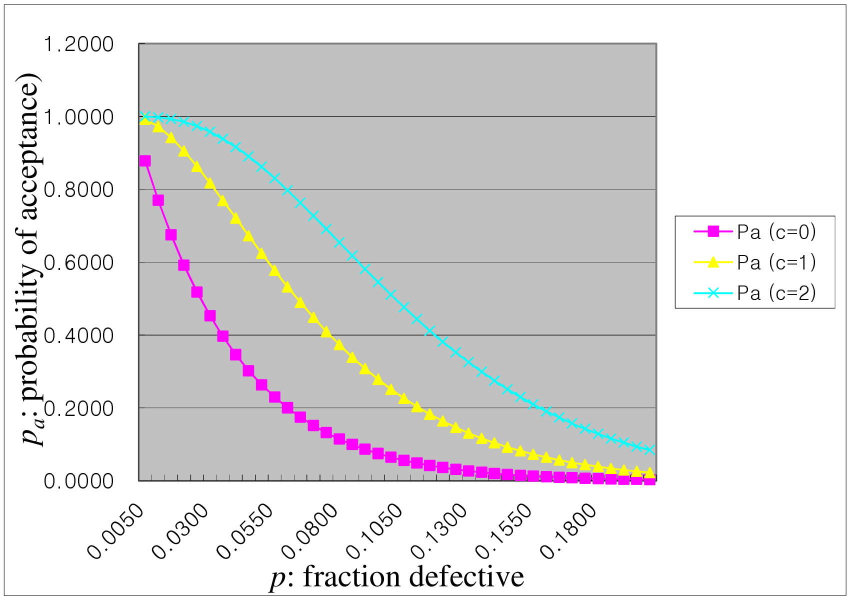

Figure 11. Operation Characteristics Curve (*x-axis: p, y-axis:* p_a) ($n=26$)

Sampling plan

The total length of the pipeline is 63.5*km* and 1/10 of the pipes are inspected yearly, which is 6.35*km*. Assuming average length of manhole-to-manhole distance (or inspection section length) is 49.6*m*, in average 128 sections are to be inspected each year. Also assuming the sample size is one-tenth of total population, the sample size n becomes 13. If the sample size is 1/5, then the number of sample, n is 26. Thus the two OC Curves for $n=13$ and $n=26$ are show in Figure 10 and Figure 11.

Acceptance policy, the value for c can be determined by the asset manager depending on how conservatively assess the average pipe condition. If c is too low, such as 0, then the acceptance rate is very low and the benefits of the sampling inspection are lost. On the other hand, if the c is too high, such as 5, acceptance rate would be very high although the real condition of the pipe is very poor.

The number of sample, n is also an important factor. Each inspection is the cost burden and the reason for the sampling is to reduce the number of inspections. However, if the number of sample is too small, the probability of incorrectly assessing the condition would increase. The management company has to determine the optimum number of sample by reviewing the OC-Curve, the Average Outgoing Quality (AOQ), and the cost of inspection.

Average Outgoing Quality (AOQ)

The maintenance company has the policy for the rectifying the inspection, which means that the company must repair all the identified defects. This results the improvement of the overall fraction defective, p. The rectifying process improves the overall quality of the products. In case of simple sampling methods, the lot is either rejected or accepted with the unknown fraction defective, p_0. For the rejected lot, complete inspection is performed and added to the out-going products. Thus, the rejected but completely inspected lot has 0 defect, improving the fraction defective of the out-going lots (Fig. 10). Although this improves the AOQ but rejected lot increases the cost of inspection.

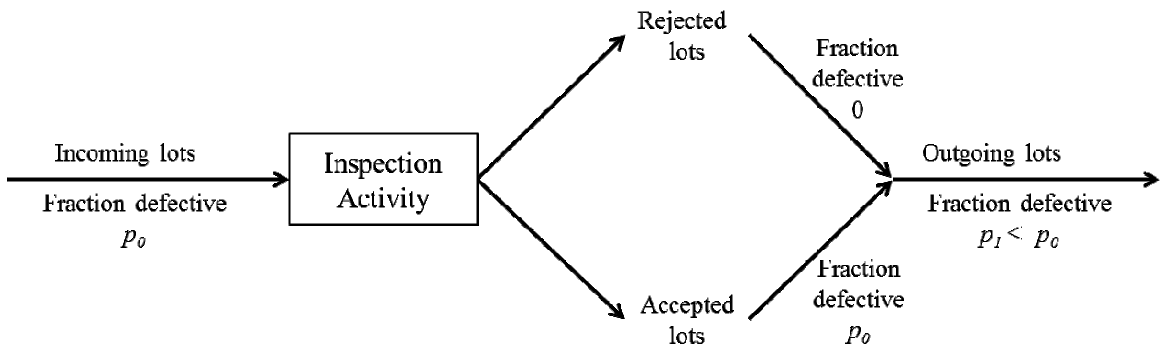

Figure 12. Rectifying Inspection (Montgomery, 2009)

Depending on the fraction defective and the acceptance policy, average outgoing quality has maxima (Fig. 11). This means that under certain acceptance policy, the worst case of the fraction defective cannot be more than the AOQ. The Average Out-going Quality (AOQ) can be obtained by multiplying p_0, p_a, when $n/N < 0.1$.

$$AOQ = p_0 p_a \frac{(N-n)}{N} \approx p_0 p_a \tag{Eq. 2}$$

It is noticeable that the maxima is found when fraction defective, p_0 is about 0.08 and 0.1. This means that when p_0 is larger than 0.1, the lot has more chance to be rejected and total inspection is performed, resulting the outgoing quality increases. When p_0 is between 0.08 and 0.1, average out-going quality is the maxima, which means the fraction defective of outgoing lot, p_1, has the largest possible value, i.e., asset condition is the worst. In other words, by acceptance sampling and rectifying inspection policy, the fraction defective, p_1 is guaranteed to be lower than the maximum AOQ.

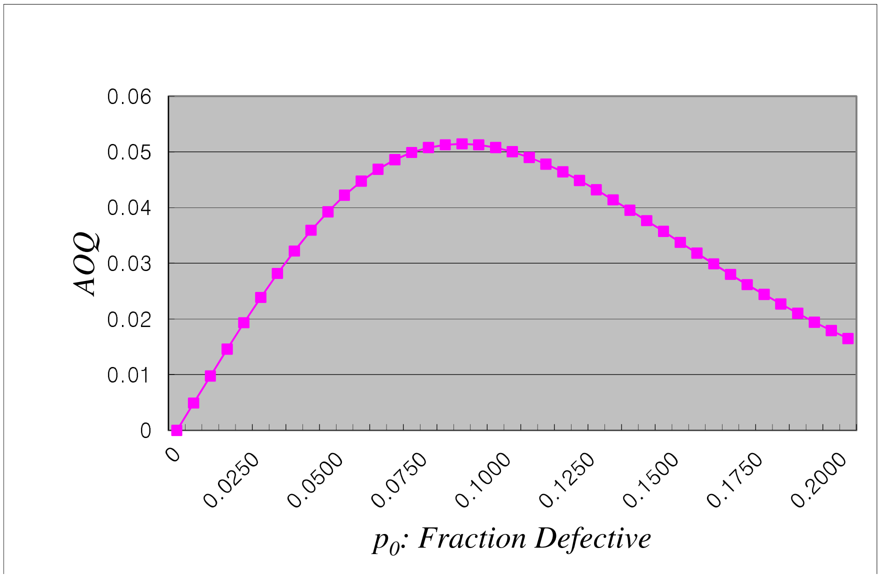

Figure 13. Average Outgoing Quality (AOQ) (*x-axis: p_0, y-axis: AOQ*) (*N= 1280, n=26, c=2*)

Sensitivity Analysis and Benefit/Cost Analysis

It requires trial and error method to find the most optimum acceptance policy and it may vary by the asset manager's policy. Conservative acceptance policy increases the rejection rate and it ends up to the total inspection and loses the benefits of the sampling. On the other hand, if the acceptance policy is too generous, the resulting quality would be low. Through the rectifying inspection policy, the AOQ can be improved however this increases the cost of inspection.

The development of the acceptance policy requires in-depth research on the maintenance company's marketing strategy, which can have alternative ways to improve the customer satisfaction level of service. For example, instead of providing zero-defect products, providing satisfactory warranty service with maintaining certain level of fraction defective would cost much less without sacrificing the company's reputation. In addition, the cost of inspection may vary depends on market and locations. In this paper, authors focused on minimizing the number of inspection while maintaining acceptable level of fraction defective.

Scenario 1: Yearly inspected pipe sections $N = 1280$, sample size $n = 26$, number of defects to accept the sample lot $c = 2$.

Maximum AOQ = 0.0514 when $p_0 = 0.085$. This means that in the worst case, the quality of pipeline asset would be 5.14% and the maintenance company would expect not more than 5.14% of defects in the asset.

The number of expected inspection can be calculated as following equation.

Expected number of inspection = $E(n) = p_a\, n + (1 - p_a)\, N$ *Eq. 3*

When $p_0 = 0.085$, $p_a = 0.6176$ and $E(n) = 505$.

Therefore, if the maintenance company maintains the N=1280, n = 26, c= 2 policy, it is expected to inspect 505 sections of pipe yearly. Which is less than half of the inspection plan without sampling plan. In addition, this guarantees the fraction defective is less than 5.14%.

Scenario 2: Yearly inspected pipe sections $N = 1280$, sample size $n = 13$, number of defects to accept the sample lot $c = 1$.

Maximum AOQ = 0.06254 when $p_0 = 0.1150$. This means that in the worst case, the quality of pipeline asset would be 6.254% and the maintenance company would expect not more than 6.254% of defects in the asset.

When $p_0 = 0.1150$, $p_a = 0.5494$ and the number of expected inspection $E(n) = 584$.

Therefore, if the maintenance company maintains the N=1280, n = 13, c= 1 policy, it is expected to inspect 584 sections of pipe yearly. Which is less than half of the inspection plan without sampling plan. In addition, this guarantees the fraction defective is less than 6.24%.

Scenario 3: Yearly inspected pipe sections $N = 1280$, sample size $n = 13$, number of defects to accept the sample lot $c = 2$.

Maximum AOQ = 0.1038 when $p_0 = 0.1650$. This means that in the worst case, the quality of pipeline asset would be 10.38% and the maintenance company would expect not more than 10.38% of defects in the asset.

When $p_0 = 0.1650$, $p_a = 0.6345$ and the number of expected inspection $E(n) = 476$.

Therefore, if the maintenance company maintains the N=1280, n = 13, c= 2 policy, it is expected to inspect 476 sections of pipe yearly. Which is less than half of the inspection plan without sampling plan. In addition, this guarantees the fraction defective is less than 10.38%.

Table 4 shows all the possible combinations for n, c, and p_o. The expected number of inspections, $E(n)$ is calculated according to n, c, and p_o. It is noticed that the expected number of inspection is abound 400 to 600. This means that regardless of the sampling policy in order to maintain certain level of AOQ, the eventual number of inspection ends to similar numbers.

The analysis shows the relationship between maximum AOQ, sample size n, and acceptance policy criteria, c. For example, if the maintenance company has the sampling policy for c=2, n=10 then the maximum AOQ is 0.1349. This means that with the sampling policy, the fraction defective of outgoing quality p_1 is lower than 13.49% for sure and if the same policy applied for multiple year, 458 sections would be inspected annually. Which is little more than 1/3 of the total inspection of the annual inspection plan. Thus the asset manager can determine the acceptance policy based on the worst case scenario of the quality of the outgoing pipeline asset condition.

Table 4. Sample size and AOQ

	When c=1			When c=2		
n	*Max AOQ*	*When p_0 is*	*E(n)*	*Max AOQ*	*When p_0 is*	*E(n)*
5	0.1589	0.275	540	0.2720	0.400	410
6	0.1333	0.235	554	0.2258	0.340	430
7	0.1148	0.205	563	0.1932	0.295	442
8	0.1008	0.180	563	0.1688	0.260	449
9	0.0898	0.165	583	0.1500	0.235	463
10	0.0810	0.150	589	0.1349	0.210	458
11	0.0738	0.135	581	0.1226	0.195	475
12	0.0677	0.125	587	0.1123	0.180	481
13	0.0625	0.115	584	0.1036	0.165	476
14	0.0581	0.110	604	0.0962	0.155	486
15	0.0543	0.100	585	0.0897	0.145	488
16	0.0509	0.095	594	0.0841	0.135	483
17	0.0479	0.090	599	0.0791	0.130	502
18	0.0453	0.085	598	0.0747	0.120	484
19	0.0429	0.080	594	0.0707	0.115	493
20	0.0407	0.075	585	0.0671	0.110	499
21	0.0388	0.075	618	0.0639	0.105	501
22	0.0370	0.070	603	0.0609	0.100	500
23	0.0354	0.070	633	0.0583	0.095	495
24	0.0339	0.065	612	0.0558	0.090	487
25	0.0325	0.065	640	0.0535	0.090	519
26	0.0313	0.060	613	0.0514	0.085	505
27	0.0301	0.060	638	0.0495	0.080	488
28	0.0290	0.055	605	0.0477	0.080	517
29	0.0280	0.055	628	0.0460	0.075	495
30	0.0270	0.050	588	0.0444	0.075	521
31	0.0262	0.050	610	0.0430	0.070	494
32	0.0253	0.050	631	0.0416	0.070	519
33	0.0245	0.050	652	0.0403	0.065	487
34	0.0238	0.045	602	0.0391	0.065	510
35	0.0231	0.045	622	0.0380	0.065	533
36	0.0225	0.045	641	0.0369	0.060	494
37	0.0218	0.045	659	0.0359	0.060	515
38	0.0213	0.040	600	0.0349	0.060	536
39	0.0207	0.040	617	0.0339	0.055	490
40	0.0202	0.040	634	0.0331	0.055	510

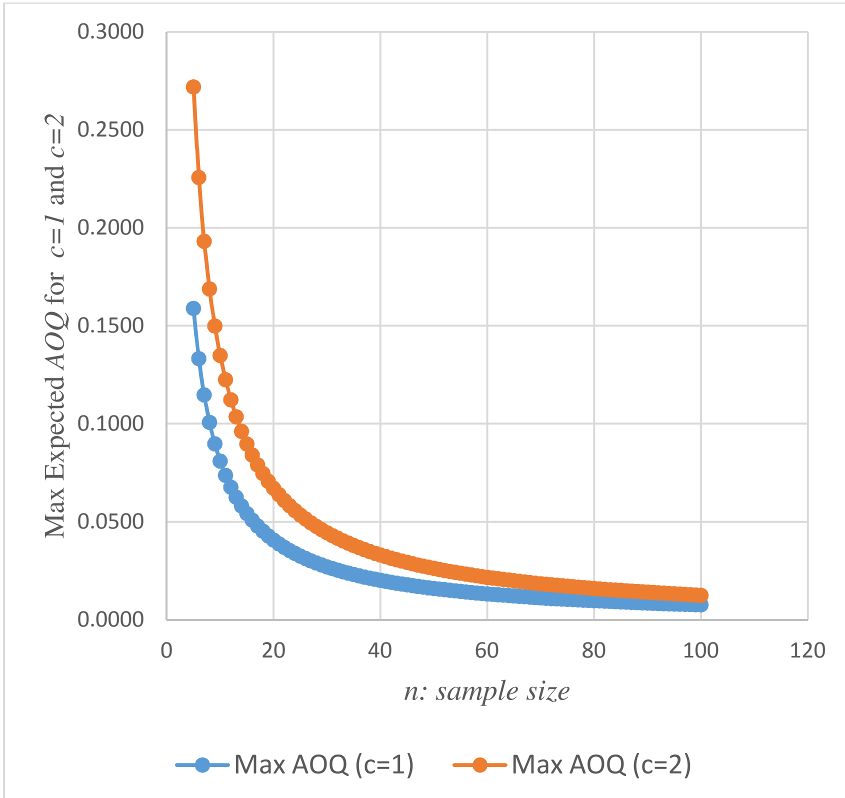

Figure 14. Maximum expected AOQ's for sample size *n*

Figure 14 shows the maximum AOQ's for two difference acceptance criteria *c*=1 and *c*=2. This also can be used as an important reference for the asset manager to develop the acceptance policy. When *n* is larger than 80, *c* =1 and *c*=2 are becoming similar while *n* is between 20 and 40 which is more realistic sample number, AOQ's are slightly different for different acceptance criteria *c*.

Summary and Conclusion

The purpose of this research is to develop the sampling strategy to find the optimum number of the sample sizes, at the same time, minimizing the risk of failure. The acceptance sampling method was applied to statistically estimate the quality of the assets, reduce the amount of inspection, save the cost of asset management.

The acceptance sampling policy determines the sample size and the criteria to accept the lot. If the policy criteria *c* is too low, rejection rate is high and this results the high cost of the inspection and reduces the advantages of the acceptance sampling. If acceptance criteria *c* is too high, the assets would have high fraction defective. Rectifying inspection policy can be applied. If the lot is rejected, total inspection is performed and repaired. Thus the average outgoing quality is better than the initial fraction defective.

The out-going quality of the asset after the acceptance sampling does not increase or decrease by the number of sample, *n* or acceptance criteria *c*. But the asset manager can expect the worst case of the asset quality depending on the *n* and *c*. Thus, the asset manager is able to identify the expected failure rate and plan in advance for the equipment and the labor for repair work.

In case of the Public Private Partnership of the social infrastructure, government controls the maintenance policy of the public facility built by private investment. Usually public entity has strict rules and risk avoidance tendency although it cost more than taking some risks and mitigating. Although sampling methods are statistically and probabilistically proven method, years of experiments and acceptance of the community are required to apply the sampling method as the policy of the public facility maintenance by the private party.

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Biographies

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