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Application of Statistical Process Control in Minimizing Defects in the Production of UPVC Sanitary Pipes

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Abstract

Introduction: Plastic processing industry is considered an important industry that supported other industries in the construction of building, establishments both commercial or industrial, housing, etc. Producing quality plastic products such as sanitary pipes are essential in the sewage conveyance, rainwater drainage, waste disposal, and the like and its quality is of prime importance. In this study, the various quality controls of Statistical Process Control (SPC) were used to minimize defects and produce quality sanitary pipes.

Objectives: This study aims to determine if there are special causes of variation in the process of producing uPVC sanitary pipes using x-bar control chart. Furthermore, the study seeks to identify the causes of these variations or defects through employing pareto chart and fishbone diagram. And also, to develop an action plan to address and minimize the defects in order to improve the quality of the uPVC pipes.

Methods: The study was conducted in the plastic manufacturing industry in Davao City, Philippines. The study employs statistical process control tools such as x-bar chart to determine if the process is statistically controlled. The pareto chart is utilized to determine the types of defects and its frequency. Lastly, fishbone diagram was utilized to determine the cause and effect of the identified defects. The study also provided an action plan based on the information given in the quality control tools used.

Results: After the study was conducted, the following were the results: the uPVC sanitary pipes sizes #2 and #4 specifically on their weight and thickness were found to be statistically not controlled using the x-bar control chart. The pareto chart revealed that defects related to weight and thickness of the pipe and the fishbone diagram presented the causes of these defects with respect to machine, man, method, and materials.

Conclusions: The Statistical Process Control tools such as x-bar chart, pareto chart, and fishbone diagram were used to study and understand the complex nature of production of uPVC sanitary pipes especially when encountering special causes of variations, also in identifying the defects and causes, so as to minimize the occurrence of these defects and improve the quality. The study concluded that the combined application of the mentioned control tools was useful in determining if the process is statistically controlled or not and in identifying the causes of common defects. The suggested action plan is based on the result of the application of the Statistical Process Control tools and is helpful in detecting and in minimizing defects in the production of uPVC sanitary pipes.

Keywords: X-bar control chart, Pareto chart, fishbone diagram, action plan uPVC sanitary pipes, weight and thickness

1. Introduction

The industry sector is important in the economic growth of any country most specifically the developing ones. In the Philippines, the plastic industry is vital to the national economy because it contributed US$ 2.3 billion in 2018 (World Bank Group, 2021). The Philippine Statistics Authority reported in their 2018 of Philippine Business and Industry: Manufacturing that there were 28,968 establishments in the formal sector of the economy engaged in manufacturing, specifically with 834 establishments plastic products manufacturing (Philippine Statististics Authority, 2020). The manufacturing of unplasticized polyvinyl chloride (uPVC) in the plastic industry sector provided a wide range of purposes from household plumbing to industrial waste management system. Sanitary pipes made up of uPVC are in-demand construction supplies, they are commonly used for sewage conveyance, rainwater drainage, waste fluid disposal, and the like. Since its purpose is critical in handling and in conveying liquid materials, the quality of these pipes is of utmost importance. A compromised quality might result to leaks, environmental pollution, and possible cost of unexpected repairs. In the study of Ginting & Supriadi (2021), the common defects for PVC pipe in a production process are melt, crack, and hollow. Among the three defects identified, the majority of the defects were melt and crack.

To avoid defects or at least minimize them, quality control is implemented by companies. Quality control carried out by the company so that the products are following predetermined standards and following the consumers' expectations (Rucitra & Amelia, 2021). Quality of products should be able to meet the quality standards consistently. One of the many approaches or techniques in ensuring quality control is the Statistical Process Control (SPC). SPC is used to determine whether the process is functioning properly or not. It is a powerful collection of problem-solving tools useful in achieving process stability and improving capability through the reduction of variability (Montgomery, 2009).

There are several applications of SPC in the industry, including the application of Quality Control tools in analyzing defects in a drum container manufacturing industry (Camelotes, et al., 2024), the use of SPC in machining (Motorcu & Gu¨llu, 2006), improving the quality of weights of animal-feed bags (Pimentel, Duat, Estrera, Sayadi, & Namoco Jr., 2022), root-cause-analysis of recurring flour packaging printing defects (Jipos, Jamito, Camelotes, Baguio, & Namoco Jr., 2023) optimization of Machine-producing uPVC pipes (Kerealme, Srirangarajalu, & Asmare, 2016), monitoring the cost and project duration of a columbarium construction project utilizing concrete composite panels (Adolph, Calibara, Estampa, Estillore, & Namoco Jr., 2022), and analyzing defects in a small-scale local shoes production company (Fuentes, Sevilla, Tabacon,, Lagamon, & Namoco Jr., 2023).

2. Objectives

This study aims to address the gap on the consistency of maintaining the technical features such as thickness of the pipe and the weight to ensure durability and longevity of the sanitary pipes. It explores the use of SPC to assess if the manufactured sanitary pipes are statistically controlled, and if there are any special causes of variations is to identify the causes to eliminate or at least minimize. Particularly, the quality tools of SPC such as x-bar control chart, Pareto chart, and fishbone diagram shall be used in the study. The result of the application of these tools will serve as an input in developing an action plan to address and minimize the defects of the uPVC sanitary pipes.

3. Methods

3.1 Research setting

The study was conducted in one of the plastic manufacturing industries in Davao City, Philippines. The company has several plastic products being manufactured, but the study is focused on the production of uPVC sanitary pipes. Particularly, the data gathered was during the quarter 1 and 2 of 2024 in the production of their pipe sizes #2 and #4.

3.2 Process of producing uPVC sanitary pipes

Just like any other manufacturing, uPVC sanitary pipes undergo several steps or process to produce the desired result. Figure 1 shows the block diagram of the process in producing sanitary pipes with sizes of #2 and #4. In the upper loader, it is where the fine ingredients pass through. The upper loader has the hopper and the feeder screw to move these fine ingredients toward the extruder. In the extruder it is where the main processing of melting and shaping the pipes with the combination of heating and air blowing. Thermocouple serves as the sensing component to set the amount of heat in the extrusion process. One important part inside the extruder is the die head. The function of a die head is to distribute the plastic evenly so that the wall thickness of the pipe is the same. Since there are three sizes of pipes the company is producing, there are also three different sizes of die heads to be placed in the extruder.

After the pipe is formed it goes inside the cooling bath to cool, solidify, and keep its shape and sizes. After that, the pipes pass through the printer section where the printing of important details of production like the date and time, size of the pipe, and name of company. Another step is the puller, it is where the pipes is being pulled slowly towards the cutting section. The cutter works to cut the pipe in the desired length of 3 meters. It has clamps to firmly hold the pipes and a sharp blade for cutting.

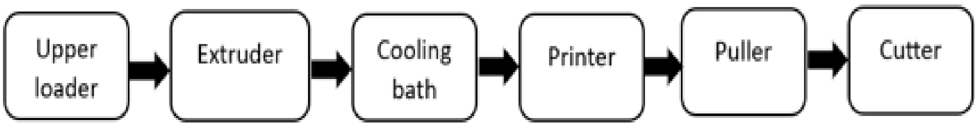

Figure 1. Block diagram of the process

3.3 Application of Statistical Process Control

The Statistical Process Control (SPC) is one of the three broad categories of Statistical Quality Control (SQC). SPC is a statistical tool that involves inspecting a random sample of the output from a process and deciding whether the process is producing products with characteristics that fall within a predetermined range. It answers the question of whether or not the process is functioning properly (Reid & Sanders, 2023). In this study the x-bar control chart, pareto chart, and fishbone diagram are utilized.

3.3.1 Use of x-bar control chart

The introduction of statistical control chart concept in 1924 by Walter A. Shewart marks the birth of Statistical Quality Control (SQC) primarily intended to control the quality of manufactured goods (Shewhart & Deming, 1986). A control chart (also called process chart or quality control chart) is a graph that shows whether a sample of data falls within the common or normal range of variation. A control chart has upper and lower control limits that separate common from assignable causes of variation. The common range of variation is defined by the use of control chart limits. We say that a process is out of control when a plot of data reveals that one or more samples fall outside the control limits (Reid & Sanders, 2023).

Control charts for variables monitor characteristics that can be measured and have a continuous scale, such as height, weight, volume, or width. An example of this is an x-bar chart which is used to monitor changes in the mean of a process. The MS Excel was used to create the x-bar chart. The following are the steps in getting the x-bar or the center line, and the control limits both upper and lower.

Step 1. Compute the mean of all sample means

To construct a mean chart, construct first the center line of the chart. To do this, take multiple samples and compute their means. Usually these samples are small, with about four or five observations. Each sample has its own mean, *x*. The center line of the chart is then computed as the mean of all *k* sample means, where *k* is the number of samples:

$$\bar{\bar{x}} = \frac{\bar{x}_1+\bar{x}_2+\ldots+\bar{x}_k}{k} \quad (1)$$

Step 2. Compute the upper and lower control limits of the chart. Use the following formula:

$$\text{UCL} = \bar{\bar{x}} + A_2\bar{R} \quad (2)$$

$$\text{LCL} = \bar{\bar{x}} - A_2\bar{R} \quad (3)$$

where:

$\bar{\bar{x}}$ = average of all the sample means
$\bar{R}$ = average range of the samples
A_2 = factor for 3 sigma control limits

Step 3. Plot the center line, upper and lower control limits using the MS Excel application.

3.3.2 Use Pareto chart

The pareto chart is one of the seven quality control tools together with the control charts. A Pareto chart is used to highlight the most frequently occurring defects, the most common causes of defects, or the most frequent causes of customer complaints (Sharma & Suri, 2017). This chart can be used when analyzing data about the frequency of problems or causes in a process and in prioritizing the most significant cause if there are multiple problems (American Society for Quality, 2024).

3.3.3 Use fishbone diagram

A fishbone diagram or Ishikawa diagram is used to identify possible causes for a problem or effect. This diagram was first introduced by a Japanese quality control statistician named Kaoru Ishikawa. The Fishbone diagram organizes observed results and their underlying causes. The diagrams' structure enables team members to think in a really systematic manner (Ilie & Ciocoiu, 2010).

4. Results and Discussion

In this study, the technical parameters measured were only thickness and weight of the uPVC sanitary pipes. The industry where the study was conducted manufactures different sizes of uPVC sanitary pipes, the sizes are #2 and #4. The sizes pertain to the outside diameter of the pipes. The coverage of the study are the pipes produced from January to May 2024.

Table 1 shows the x-bar chart of the thickness of #2 pipe produced on January 8-9, 2024. There were 25 samples and each sample has four observations. The unit of measurement for the thickness is in millimeter (mm). The mean of all sample means was 2.799, this value corresponds to the center line of the chart. The average range is 0.396. The upper limit is 3.088 while the lower control limit value is 2.51.

Figure 2 shows the resulting control x-bar chart for the thickness of uPVC pipe size #2. It can be seen that sample number 1, 8, 10, and 11 were having an average of 3.15, 3.15, 3.15, and 3.2 respectively were found to be outside the upper control limit of 3.088. Having

Table 1. X-bar chart of uPVC #2 thickness

Sample No.	Number of Observations				Average	Range	X-bar Control limits		
	1	2	3	4			CL	UCL	LCL
1	3.2	3.5	3.3	2.6	3.15	0.9	2.799	3.088	2.510
2	2.5	2.8	2.7	2.5	2.625	0.3	2.799	3.088	2.510
3	2.6	2.7	2.7	2.6	2.65	0.1	2.799	3.088	2.510
4	2.5	2.8	3	2.7	2.75	0.5	2.799	3.088	2.510
5	2.6	2.8	2.7	2.7	2.7	0.2	2.799	3.088	2.510
6	2.5	2.8	2.7	2.7	2.675	0.3	2.799	3.088	2.510
7	2.7	2.7	2.7	2.6	2.675	0.1	2.799	3.088	2.510
8	3.3	3.2	3	3.1	3.15	0.3	2.799	3.088	2.510
9	2.7	2.8	3	2.7	2.8	0.3	2.799	3.088	2.510
10	3.1	3.5	3	3	3.15	0.5	2.799	3.088	2.510
11	3.3	3.5	3	3	3.2	0.5	2.799	3.088	2.510
12	3	2.8	2.7	2.7	2.8	0.3	2.799	3.088	2.510
13	3.6	2.7	2.6	2.5	2.85	1.1	2.799	3.088	2.510
14	3	2.8	2.5	2.6	2.725	0.5	2.799	3.088	2.510
15	3	2.8	2.5	2.5	2.7	0.5	2.799	3.088	2.510
16	2.7	2.9	2.7	2.7	2.75	0.2	2.799	3.088	2.510
17	2.8	2.7	2.6	2.6	2.675	0.2	2.799	3.088	2.510
18	2.7	2.7	2.6	2.7	2.675	0.1	2.799	3.088	2.510
19	2.9	2.7	2.7	2.6	2.725	0.3	2.799	3.088	2.510
20	2.7	3	2.7	2.6	2.75	0.4	2.799	3.088	2.510
21	2.8	3.1	2.8	2.7	2.85	0.4	2.799	3.088	2.510
22	2.7	2.7	2.6	2.7	2.675	0.1	2.799	3.088	2.510
23	3.2	2.7	2.6	2.6	2.775	0.6	2.799	3.088	2.510
24	2.8	2.7	2.5	2.6	2.65	0.3	2.799	3.088	2.510
25	3.5	2.7	2.6	2.6	2.85	0.9	2.799	3.088	2.510

$(\bar{\bar{x}})$ =2.799 $(\bar{R})$ =0.396

samples that are outside the control limits provided an information that the process is not statistically controlled. There is a special cause of variation that should be identified because this makes the process not stable.

For the weight of uPVC sanitary pipe #2, Table 2 shows the x-bar chart. The unit of measurement for the weight is kilogram (kg). The mean of all sample means is 2.027 while the average range is 0.044. The upper control limit is set at 2.059 and the lower control limit is at 1.994. Figure 3 shows the resulting control x-bar chart for the weight of uPVC pipe size #2. It can be seen that sample number 1, 8, 10, 11, and 25 were having an average of 2.076, 2.063, 2.06, 2.06 and 2.066 respectively were found to be outside the upper control limit of 2.063. Having samples that are outside the control limits provided an information that the process

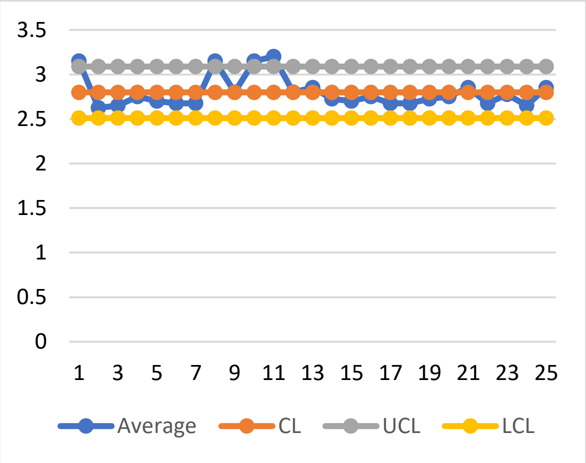

Figure 2. Resulting control x-bar chart of uPVC #2 thickness

Table 2. X-bar chart of uPVC #2 weight

Sample No.	Number of Observations				Average	Range	X-bar Control limits		
	1	2	3	4			CL	UCL	LCL
1	2.098	2.089	2.092	2.025	2.076	0.073	2.027	2.059	1.994
2	2.002	2.003	2.015	2.001	2.005	0.014	2.027	2.059	1.994
3	2.014	2.205	2.004	2	2.056	0.205	2.027	2.059	1.994
4	2.015	2.035	2.015	2.09	2.039	0.075	2.027	2.059	1.994
5	2.015	1.973	2.015	2.01	2.003	0.042	2.027	2.059	1.994
6	2.07	2.012	2.025	2.004	2.028	0.066	2.027	2.059	1.994
7	1.998	2.012	2.005	2.01	2.006	0.014	2.027	2.059	1.994
8	2.124	2.041	2.046	2.042	2.063	0.083	2.027	2.059	1.994
9	2.022	2.016	2.003	2.019	2.015	0.019	2.027	2.059	1.994
10	2.055	2.052	2.08	2.054	2.060	0.028	2.027	2.059	1.994
11	2.053	2.065	2.058	2.062	2.060	0.012	2.027	2.059	1.994
12	2.012	2.003	2.019	2.008	2.011	0.016	2.027	2.059	1.994
13	2.118	2.005	2.016	1.996	2.034	0.122	2.027	2.059	1.994
14	2.011	2.009	1.995	2.014	2.007	0.019	2.027	2.059	1.994
15	2.004	2.015	2.025	2.025	2.017	0.021	2.027	2.059	1.994
16	2.003	2.011	2.005	1.997	2.004	0.014	2.027	2.059	1.994
17	2.003	2.011	2.009	2.001	2.006	0.01	2.027	2.059	1.994
18	2.003	2.002	2.022	2.015	2.011	0.02	2.027	2.059	1.994
19	2.028	2.02	2.025	2.044	2.029	0.024	2.027	2.059	1.994
20	2.003	2.006	2.008	2.01	2.007	0.007	2.027	2.059	1.994
21	2.012	2.002	2.023	2.003	2.010	0.021	2.027	2.059	1.994
22	2.03	2.026	2.037	2.035	2.032	0.011	2.027	2.059	1.994
23	2.013	1.998	1.998	2.018	2.007	0.02	2.027	2.059	1.994
24	2.016	2.017	2.012	2.01	2.014	0.007	2.027	2.059	1.994
25	2.184	2.025	2.025	2.03	2.066	0.159	2.027	2.059	1.994

$(\bar{\bar{x}})$ =2.027 $(\bar{R})$ =0.044

is not statistically controlled. There is a special cause of variation that should be identified because this makes the process not stable.

For the thickness of uPVC pipe # 4, the data was taken during the production of the pipe on April 30 – May 2, 2024. The same with pipe # 2, the pipe #4 had 25 samples with 4 observations per sample taken. The Table 3 shows the x-bar chart of the thickness of #4 pipe. The mean of all sample means was 4.106, this value corresponds to the center line of the chart. The average range is 0.416. The upper limit is 4.410 while the lower control limit value is 3.802.

Figure 4 shows the resulting control x-bar chart for the thickness of uPVC pipe size #4. It can be seen that sample number 1, 2, and 18 were having an average of 4.425, 4.475, and 4.45 respectively, were found to be

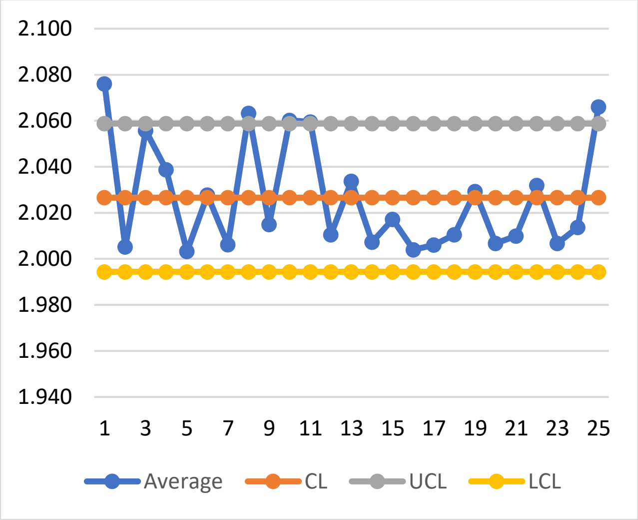

Figure 3. Resulting control x-bar chart of uPVC #2 weight

Table 3. X-bar chart of uPVC #4 thickness

Sample No.	Number of Observations				Average	Range	X-bar Control limits		
	1	2	3	4			CL	UCL	LCL
1	4.3	4.5	4.5	4.4	4.425	0.2	4.106	4.410	3.802
2	4.4	4.4	4.5	4.6	4.475	0.2	4.106	4.410	3.802
3	3.8	4.2	4.3	4.1	4.1	0.5	4.106	4.410	3.802
4	3.8	4	4.5	4.3	4.15	0.7	4.106	4.410	3.802
5	4	3.8	4.6	4.1	4.125	0.8	4.106	4.410	3.802
6	4.1	3.8	4.5	4	4.1	0.7	4.106	4.410	3.802
7	3.8	3.8	4.4	4	4	0.6	4.106	4.410	3.802
8	3.9	4	4.4	4.2	4.125	0.5	4.106	4.410	3.802
9	4.2	3.9	4.3	4.2	4.15	0.4	4.106	4.410	3.802
10	3.8	3.8	4.3	4.1	4	0.5	4.106	4.410	3.802
11	3.9	3.9	4.3	4.1	4.05	0.4	4.106	4.410	3.802
12	3.8	3.9	4.5	4.4	4.15	0.7	4.106	4.410	3.802
13	4	3.8	4.1	4.1	4	0.3	4.106	4.410	3.802
14	3.9	3.8	4	4	3.925	0.2	4.106	4.410	3.802
15	3.8	3.7	4.3	4	3.95	0.6	4.106	4.410	3.802
16	4	3.8	4.7	4.1	4.15	0.9	4.106	4.410	3.802
17	3.8	4	4	4	3.95	0.2	4.106	4.410	3.802
18	4.4	4.5	4.4	4.5	4.45	0.1	4.106	4.410	3.802
19	4.1	4	4.1	4.2	4.1	0.2	4.106	4.410	3.802
20	4	3.9	4	4.2	4.025	0.3	4.106	4.410	3.802
21	4.2	3.8	4.1	4.4	4.125	0.6	4.106	4.410	3.802
22	4	4	4.2	4	4.05	0.2	4.106	4.410	3.802
23	4.1	3.9	4.1	4.1	4.05	0.2	4.106	4.410	3.802
24	4	3.9	4.1	4	4	0.2	4.106	4.410	3.802
25	4	3.9	4.1	4.1	4.025	0.2	4.106	4.410	3.802

$(\bar{\bar{x}})$ =4.106 $(\bar{R})$ =0.416

outside the upper control limit of 4.410. Having samples that are outside the control limits provided an information that the process is not statistically controlled. There is a special cause of variation that should be identified because this makes the process not stable.

The weight uPVC sanitary pipe size # 4 is shown in Table 4 including its complete x-bar chart. The mean of all sample means is 5.800 while the average range is 0.198. The upper control limit is set at 5.945 and the lower control limit is at 5.655.

Figure 5 shows the resulting control x-bar chart for the weight of uPVC pipe size #4. There were three samples that were outside the control limits. These samples were 1 with an average weight of 5.968, sample number 2 with an average weight of 5.976 and

Figure 4. Resulting control x-bar chart of uPVC #4 thickness

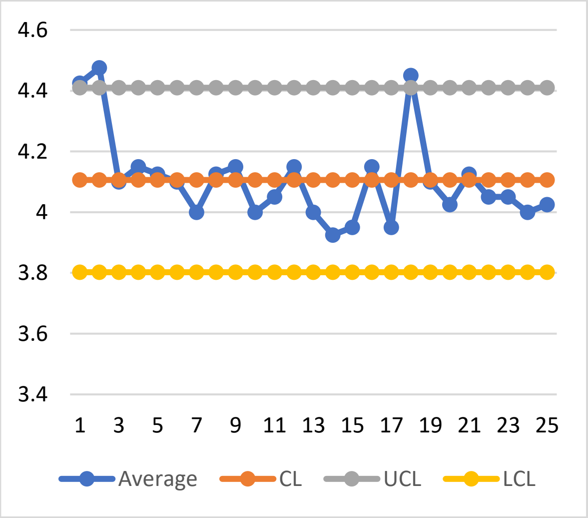

Table 4. X-bar chart of uPVC #4 weight

Sample No.	Number of Observations				Average	Range	X-bar Control limits		
	1	2	3	4			CL	UCL	LCL
1	5.899	6.193	5.841	5.937	5.968	0.352	5.800	5.945	5.655
2	5.986	5.958	5.984	5.977	5.976	0.028	5.800	5.945	5.655
3	5.834	5.696	5.768	5.699	5.749	0.138	5.800	5.945	5.655
4	5.639	5.74	5.733	5.653	5.691	0.101	5.800	5.945	5.655
5	5.735	5.831	5.965	5.798	5.832	0.23	5.800	5.945	5.655
6	5.835	5.663	5.789	5.635	5.731	0.2	5.800	5.945	5.655
7	5.646	5.961	5.774	5.655	5.759	0.315	5.800	5.945	5.655
8	5.669	5.669	5.801	5.62	5.690	0.181	5.800	5.945	5.655
9	5.708	5.682	5.791	5.629	5.703	0.162	5.800	5.945	5.655
10	5.995	5.683	5.767	5.698	5.786	0.312	5.800	5.945	5.655
11	5.706	5.647	5.787	5.75	5.723	0.14	5.800	5.945	5.655
12	5.775	5.836	5.879	5.784	5.819	0.104	5.800	5.945	5.655
13	5.774	5.666	5.786	5.725	5.738	0.12	5.800	5.945	5.655
14	5.78	5.721	5.803	5.708	5.753	0.095	5.800	5.945	5.655
15	5.792	5.968	5.806	5.703	5.817	0.265	5.800	5.945	5.655
16	5.783	5.68	5.779	5.725	5.742	0.103	5.800	5.945	5.655
17	5.798	5.931	5.808	5.704	5.810	0.227	5.800	5.945	5.655
18	5.996	5.988	5.924	5.985	5.973	0.072	5.800	5.945	5.655
19	5.939	5.936	5.714	5.963	5.888	0.249	5.800	5.945	5.655
20	5.914	5.632	5.797	5.724	5.767	0.282	5.800	5.945	5.655
21	5.978	5.671	5.712	5.726	5.772	0.307	5.800	5.945	5.655
22	5.74	5.938	5.965	5.991	5.909	0.251	5.800	5.945	5.655
23	5.923	5.684	5.768	5.705	5.770	0.239	5.800	5.945	5.655
24	5.902	5.627	5.7	5.707	5.734	0.275	5.800	5.945	5.655
25	6.002	5.947	5.869	5.795	5.903	0.207	5.800	5.945	5.655

$(\bar{\bar{x}})$ =5.800 $(\bar{R})$ =0.198

sample number 18 with an average of 5.973. Having samples that are outside the control limits provided an information that the process is not statistically controlled. There is a special cause of variation that should be identified because this makes the process not stable.

After implementing the control charts, the head of the operations was asked by the researcher on the usual defects they encountered during the production of these pipes. Using the pareto chart, Figure 6 shows the common defects and its frequency generated in a production cycle. Also, this chart will help explain in which of the common defects should be prioritized to address the encountered problems and improve customer satisfaction. Based on the pareto chart, it can be seen that defects related to weight occupied the top two common defects in the uPVC pipe production

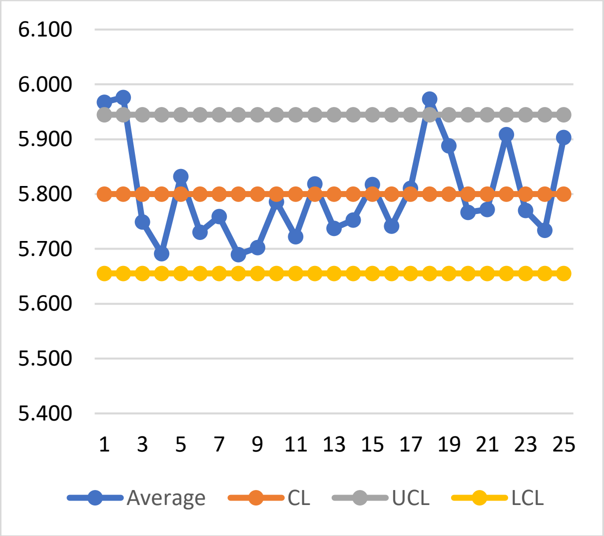

Figure 5. Resulting control x-bar chart of uPVC #4 weight

followed by too thick, melted, and crack to complete the top five frequent defects. The common defects for PVC pipe in a production process are melt, crack, and hollow. Among the three defects identified, the majority of the defects were melt and crack (Ginting & Supriadi, 2021).

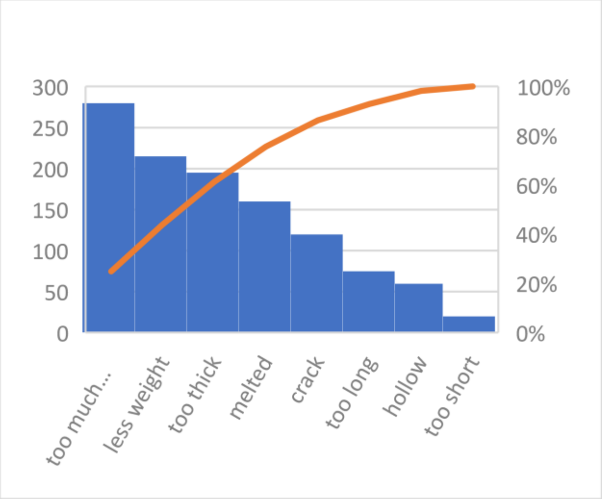

Figure 6. Pareto chart of the common defects of uPVC pipe

After finding the common defects, it is helpful to understand their causes using the Ishikawa or fishbone diagram. Figure 7 shows the fishbone diagram of this study for the root-cause-analysis. The diagram explains the causes and were categorized into four major groups namely man, method, machine, and materials. For the man, it contributed to the defects because of not being capable to operate the machines. This happened because there is no proper training for all its personnel. When they were hired, the company did not have a formal training and in fact their minimum qualifications do not match the needed skills and competencies. They just learn how to operate when they were already assigned in the production. Another associated cause is the staffing and assignment issues which becomes a concern because there are other personnel who are not willing to learn or explore and take initiative to get to know the machines and how they are being operated.

For the method, one incident happened in the production of the pipes when a certain employee encountered accident due to lack of knowledge on Occupational Health and Safety procedures, so it affected the operation. Another category is about the machine, the extruder part houses the heaters and air blowers for the forming and shaping the pipes. The causes were identified when there is insufficient amount of heat and air-blowing due to defective thermocouples and incorrect control setting. Another cause is the vibration of the cutter which is caused by the misalignment of its clampers. And lastly, the materials. They have difficulty in mixing the ingredients and provide correct control setting for proper heating and air blowing because the materials or ingredients delivered were not the same as the other batches of materials delivered before. The central office failed to communicate and inform the regional office on the type of ingredients and materials used to also have the correct setting for the operation.

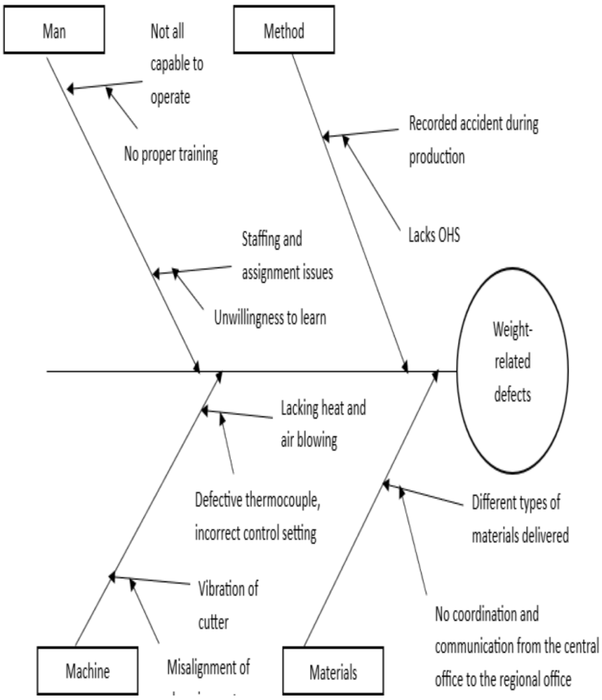

Figure 7. Fishbone diagram of weight-related defects

With the information presented in the various quality controls of SPC, it gives insight on how to address these causes so that the special causes of variations are removed to make production statistically controlled. Table 5 shows the possible action plan to suggest courses of action to be taken to address the special causes of variation. It shows the various categories of issues encountered with the corresponding specific action as well as recommendation to be done by the concerned industry. Recommendations such as development of specific job description with the required skills and competencies for the job and conduct or provide training for all the personnel relative to the assignment of job in the production. Those were the example recommendation for the category of man. Table 5 shows the complete action plan to help minimize the defects in the production of uPVC sanitary pipes.

Table 5. Action Plan

Issue	Action	Recommendation
Man		
1. Not all capable to operate	Conduct in-house training for personnel in the production	Develop specific job description including the needed skills and competencies for the job. Provide training to all personnel to familiarize and understand the operation of machines
2. Staffing and assignment issues	Rotation of personnel	Provide schedule of rotation of personnel so it becomes periodic and everyone has the chance to be assigned to different areas of production
Machine		
1. Lacking heat and airblowing	recording of temperature setting and other parameters	Develop a control setting of various parameters such as temperature, speed, air, etc. to standardize the setting
2. Vibration of cutter	secure the cutter machine in a level surface	Plan the physical setup of various machines
	regular checking of the cutter	Preventive maintenance for all the different machines in the production
Method		
1. Recorded accident in the production	constantly remind them of the safety protocols	Train the personnel about Occupational Health and Safety
Materials		
1. Different types of materials delivered	Communicate to the central office on the types of materials	Provide a list of setting needed for different types or sets of materials to achieve the desired result of heating and melting of ingredients.

5. Conclusion

The availability of different quality control tools of Statistical Process Control (SPC) was beneficial in addressing significant problems in the production of uPVC sanitary pipes in plastic industry. Specifically, the x-bar chart, pareto chart, and fishbone diagram were used to study and understand the complex nature of production of sanitary pipes especially when encountering special causes of variations, into identifying the defects and their associated causes. In addition to the existing study that melt and crack were common defects of pipes, this study showed that additional thickness and excess weight of the pipes were defects found. The excess of weight and too much thickness will incur more materials in the production and may pose associated irregularities when combined with other construction materials in the construction services. With the sizes of pipes namely #2, and #4 both have shown that they experienced special causes of variation. They have recorded observations that their averages were outside the control limits. This means that there are special causes of variations that made the process unstable as reflected in the x-bar chart.

Since there were special causes of variation, the Pareto chart was used to identify the defects as well as its frequency so the management knows which of the defects should be prioritized. The pareto chart showed that defects associated to excessive weight and thickness and melted were the top three common defects. The Fishbone diagram illustrated the various categories of man, method, machine, and materials helped in explaining the causes of these defects. Finally, an action plan was provided as a recommendation to help address the defects and its causes so the special causes of variations as shown in the x-bar control charts are resolved. By doing so, it may make the process stable because the special causes of variations were already removed and what remained are the inherent or internal causes which are acceptable in the process. Through the application of the combine quality control tools the defects in manufacturing uPVC pipes are minimized.

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