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Optimization of Production Throughput and Quality Control Metrics: A Case Study in Home Appliance Assembly

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ABSTRACT

The given research paper is a rather detailed quantitative study of the daily and monthly production rates and defects in the production of home appliances in the General Company of Light Industry, Iraq, in the first quarter of 2026. Three different product lines have been studied in terms of the 10-foot vertical display unit (January), 2-door display unit (February), and 3-door display unit (March). The methods of statistical process control (SPC) such as p-control chart and Pareto analysis were used to describe the defects occurrences, out-of-control conditions and the root causes. Total production volumes were 1,250, 360, and 250 units, with overall efficiencies of 96.72%, 94.17%, and 90.80% respectively. The overall rate of rejection in all three months was 4.07% (75 rejected out of 1,860 total units). The most common types of defects were injection mold (March), shortages in the quantity of the foam (all months), and external structural damage (January and March). Ishikawa analysis was applied to trace the causes systematically to materials, machine conditions, human factors, and environmental disturbances such as lack of power. Recommendations that combine Six Sigma DMAIC approach, preventive maintenance regimes and corrective process controls to operational excellence are provided.

1. Introduction

Quality control in manufacturing is a foundation of global economic industrial competitiveness. In the case of home appliance manufacturers in developing economies, the dilemma of ensuring a steady quality of its products and limiting resources with instability of infrastructure and variability of the workforce is especially acute. The General Company of Light Industry (GCLI) is an Iraqi manufacturer of various vertical display units - refrigeration appliances popularly used in commercial and retail space. Such products require high accuracy in assembly, foam injection procedures and structural integrity to comply with the market demands.

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The first quarter of 2026 was quite diverse in its operations with three different product lines manufactured consecutively during January, February and March. The products lines, 10-foot single-door vertical display unit, the 2-door display unit, and the 3-door display unit, had different production difficulties, defects, and process control needs. This statistical behavior of daily production and defect rates is vital to not only take corrective action immediately, but also enhance it in the end.

Statistical Process Control (SPC) offers a sound methodology to track production processes and identify common-cause variation and assignable-cause variation. The P-chart is a chart that can be used to monitor the percentage of nonconforming items in variable-sized subgroups, especially in manufacturing scenarios where the size of a daily batch can vary or where specific days may have zero production due to maintenance, weekends or even public holidays [1]. Pareto analysis, which is based on the empirical data that a small proportion of causes produce most of the effects, provides a prioritization mechanism of quality improvement initiatives [2].

The importance of combined SPC-Pareto has always been proven in prior studies in the field of quality control in the appliance manufacturing. Research conducted by Montgomery [3] laid the theoretical basis of the application of P-chart in high volume manufacturing. Juran bases the Pareto methodology used in this work on the quality management principles [4]. Studies carried out at similar Iraqi industrial plants have also pointed out instability in power supply as a systemic issue that has been experienced in the foam injection processes in the specific case [5]. Comparisons with like case studies in appliance manufacturing in other developing economies show that mold defects and lack of materials are some of the most common types of defects worldwide [6].

The following three research objectives were considered in the present study: (1) to quantitatively describe the production efficiency and rejection rates in the first quarter 2026 of all of the three product lines; (2) to use SPC P-charts to show when the production processes lacked statistical stability; (3) to carry out Pareto analysis and root-cause investigations of significant defect categories, which would allow making evidence-based recommendations. The results add an empirical evidence to the literature of industrial engineering on manufacturing quality in the home appliance industry and offer practical advice to the plant management.

2. Literature Review

2.1 Statistical Process Control in Manufacturing

First formalised by Walter A. Shewhart in the 1920s at Bell Laboratories, Statistical Process Control has since become one of the most popular tools of industrial quality management. The main concept of SPC is that can be applied control charts to differentiate common-cause variation (which is natural in every process) and special-cause variation, which indicates that the process has been disrupted by something that can be identified and needs investigation [7]. Control charts are real-time monitoring tools that are used in manufacturing settings by initiating corrective measures before the nonconforming products build up in huge numbers.

The P-chart (proportion defective chart) is created to be used on attribute data in which the individual inspection unit is either a conforming or a nonconforming unit. As opposed to the use of variable control charts (X-bar and R charts) that demand the availability of measurement data, P-chart is suitable when the characteristics of products can only be evaluated using binary pass/fail criteria [8]. The P-chart control limits are based on the binomial distribution and are adjustable to different subgroup sizes, thereby being suitable in production settings that do not have an equal amount of daily output. Some authors have observed that P-charts are especially useful in identifying process changes related to change in raw material, operator error or wear of machines [9].

The use of SPC in the production of home appliances has been reported in a wide range of production environments. Krajewski et al. [10] showed that there were considerable defect rate reductions after implementing SPC in the line assembly of refrigerators within Eastern Europe. The loss function framework by Taguchi has been implemented to the foam injection process specifically and the cost implications of overdressing the foam density and volume has been emphasized. In more recent times, the combination of SPC and real-time sensor data of Industry 4.0 technologies has introduced new opportunities of predictive quality control [12], yet these more sophisticated methods are not accessible to the majority of plants in developing economies.

2.2 Pareto Analysis and Defect Prioritization

The Pareto Principle or the 80-20 rule is a rule that states that 80 per cent of problems are caused by 20 per cent of causes. This principle is applied in manufacturing quality control to direct how much effort should be devoted to improvement efforts according to the most impactful categories of defects. Pareto analysis was popularized as a quality management tool in the 1950s by Joseph M. Juran, and is still a pillar of the Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) framework [4].

Pareto charts, an integration of bar charts (with absolute defect frequencies) and a cumulative percentage line, allow practitioners to visually identify the most important few causes of most quality failures, the vital few. In manufacturing of appliances, there has always been a limited number of defect types (usually three to five different types) which cause more than 75 percent of all rejection [13]. Typical prevailing classifications in the manufacture of the refrigeration appliances are the foam deficiency or injection, structural damages to external or internal parts, mould defects, and glazing failure [14].

Further expounded in the Ishikawa (fishbone or cause-and-effect) diagrams, which graphically systematize the possible causes of defects within six dimensions: materials, machine, methods, measurement, environment, and human factors (the 6M framework) [15], the relationship between defect prioritization and root-cause analysis is promoted. Pareto analysis and Ishikawa diagrams combined into a potent diagnostic toolkit, directing the targeted corrective measures and the process enhancement.

2.3 Home Appliance Manufacturing Quality Challenges in Developing Economies

The quality issues encountered by manufacturing plants in developing economies are unique and different in nature and magnitude compared to the problems encountered in industrialized countries. One of the most common reasons given to impede consistency of the manufacturing process is the lack of infrastructure especially the unreliability of electricity supply. When using foam injection to insulate appliances, the appliances may become ineffective due to power interruptions, which in turn may leave the insulation of the appliance incomplete, leaving the appliance with insulation void [16].

In a 2024 case study at the same GCLI plant, dedicated to 13-foot vertical display units [6], it was reported that instability of power supply was the cause of 55.6% of all the defects that were identified during four months of production. This observation is consistent with the general literature on Iraqi industrial facilities, as reliability of electrical grids has been found to be a key operational risk factor in such facilities [17]. The data of 2026 investigated in the current research enables a comparison between product lines and calendar intervals, which is a more detailed insight into the dynamics of defect causation.

The role of human factors in quality in the manufacturing of appliances is also important. It has linked external structural damage and assembling errors to worker negligence, lack of skills, and fatigue in related plants [18]. The use of standardized working methods, visual management, and error-proofing (poka-yoke) systems have been suggested as counter time measures in the literature [19]. The current study critically appraises the contribution of human, machine, material, and environmental factors to the defect profiles that occur in the first quarter of 2026.

3. Research Methodology

3.1 Data Source and Collection

The official production inspection reports of the General Company of Light Industry, Iraq, during the first quarter of 2026 (January, February, and March) were used to obtain the data of this study. Three inspection report sheets were kept one of which was the 10-foot vertical display unit, which was manufactured in January 2026; the other was the 2-door display unit, which was manufactured in February 2026; and the third, the 3-door display unit, which was manufactured in March 2026.

The inspection records recorded the date of production, number of units produced, number of units accepted, and number of units rejected and some notes on nature of observed defects in every production day. Zero production days were considered non-working days (weekends, official holidays) or maintenance days of the machinery and were not included in the calculation of rates but were left in the chronological register. In March 2026, there was an Eid Al-Fitr public holiday and two non-production days at the end of the month, explicitly annotated in the original data.

3.2 Analytical Framework

The analytical approach used in the research was done in four steps. In the first place, descriptive statistics were calculated on each monthly dataset, which consist of total and mean daily production, mean daily rejection rate, standard deviation of daily rejection rates and the overall efficiency of production. Second, P-control charts were built to evaluate stability of the process where control limits were determined based on the standard SPC methodology. Third, the Pareto analysis has been used on the defect-cause data, which were taken out of the notes field of every inspection record, and it made it possible to identify the most frequent defect types. Fourth, an Ishikawa diagram was used to trace the cause of the defect categories identified in a systematic manner.

3.3 P-Chart Construction

The following statistical formulas were used to plot the P-chart of every monthly dataset. The centerline (mean proportion defective) was calculated as:

$$\bar{p} = \Sigma d_i / \Sigma n_i$$

and where d_i is the number of units rejected on day i, and n_i is the number of units produced on day i. The binomial approximation was used to calculate the upper and lower control limits (UCL and LCL):

$$UCL = \bar{p} + 3\sqrt{[\bar{p}(1-\bar{p})/\bar{n}]} \quad LCL = \max\{0, \bar{p} - 3\sqrt{[\bar{p}(1-\bar{p})/\bar{n}]}\}$$

where $\bar{n}$ is the average size of subgroups (average daily production over days of production). The three-sigma limits are derived to represent a probability boundary of 99.73% with the assumption that the binomial process is stable. Points that were plotted outside the UCL were marked as out-of-control signals that needed to be investigated on the assignable cause [3].

The P-chart subgroups did not include production days where zero production was recorded since they do not help to estimate the proportion of defects. This is in line with common practice in SPC in intermittent production schedules [8].

3.4 Pareto Analysis Protocol

The categories of defects were identified by means of the textual notes made in the inspection sheets and translated into the Arabic to standard category names in English. Each month, the number of defects per category on all production days were counted. Each category was ranked by frequency, and a cumulative percentage curve plotted on top, to determine the 80% threshold - the point at which the most common categories as a whole explain 80% of all defects. This critical number determines the vital few causes that should be given priority as corrective action [2].

3.5 Production Efficiency Metric

The efficiency (PE) of production per month was determined as the ratio of the total production units to the total accepted units per month as a percentage:

$$PE\ (\%) = (\text{Total Accepted} / \text{Total Produced}) \times 100$$

This measure gives a direct indication of the manufacturing yield and it is a complement to the defect rate (DR = 100% - PE). The two measures are calculated at a daily and monthly level to allow a temporal comparison of the production steadiness.

4. Data Presentation and Descriptive Statistics

4.1 Overview of first quarter 2026 Production Data

The overall production performance in the three months of first quarter 2026 is summarized in Table 1. January data of the 10-foot vertical display unit show the maximum absolute volume of production at 1,250, which is in line with the high capacity production line of the facility in this category of products. The February 2-door display unit production comprised 360 units with 15 units in each batch and 250 units in each batch in March 3-door display unit production respectively.

Table 1: First quarter 2026 Production Summary — All Product Lines

Parameter	January (10-ft Vertical)	February (2-Door)	March (3-Door)	First Quarter Total	Units
Total Production Days (Calendar)	31	28	31	90	days
Working Production Days	25	24	25	74	days
Non-Production Days	6	4	6 (incl. 2 Eid)	16	days
Total Units Produced	1,250	360	250	1,860	units
Total Units Accepted	1,209	339	247	1,795	units
Total Units Rejected	41	21	13	75	units
Overall Production Efficiency	96.72%	94.17%	90.80%	96.50%	%
Overall Rejection Rate	3.28%	5.83%	5.20%	4.03%	%
Target Daily Batch Size	50	15	10	—	units/day
Defect Days (days with rejections > 0)	10 / 25	11 / 24	8 / 25	29 / 74	days

The visual comparison of the total units produced, accepted and rejected within the three lines of products is shown in Figure 1. The January product line is highest in terms of absolute volume as it has a bigger batch size (50 units/day compared to 15 and 10 units/day with February and March respectively). Interestingly, the absolute rejection rate (41 units) is the highest, though; the efficiency rate is the highest in January (96.72 percent), indicating that the higher absolute volume compensates the lower proportional defect rate of January.

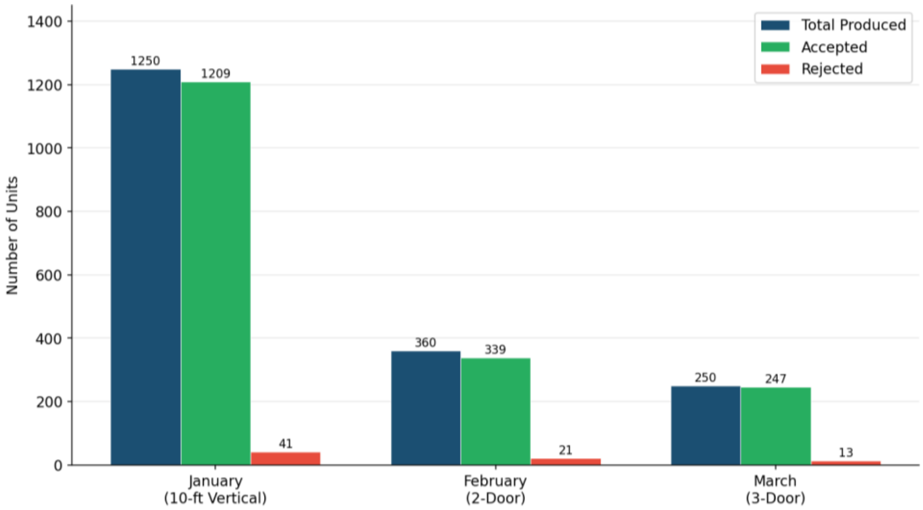


Figure 1: Monthly Production Summary - first quarter 2026 (Grouped Bar Chart with total units produced, accepted, and rejected by product line)

4.2 January 2026 — 10-foot Vertical Display Unit

The January data includes 31 calendar days that include 25 active production days where the batch size is always 50 units/day. There were six days of no production which is about 19.4% of the calendar days and equates to weekends and a public holiday. Out of the 25 days of production, 10 days (40 percent) had at least one unit rejected in the process, which means that defects were spread over a considerable part of working month.

Table 2: January 2026 — Days with Defects (10-ft Vertical Display Unit)

Day	Date	Produced	Accepted	Rejected	Defect Notes
2	02 Jan	50	49	1	Mold Defect
5	05 Jan	50	46	4	External Structure Damage
7	07 Jan	50	44	6	Foam Quantity Shortage
8	08 Jan	50	47	3	External Structure Damage
9	09 Jan	50	48	2	External Structure Damage
13	13 Jan	50	44	6	Foam Quantity Shortage
14	14 Jan	50	48	2	External Structure Damage
19	19 Jan	50	40	10	Foam Quantity Shortage
25	25 Jan	50	48	2	Glass Door Breakage
26	26 Jan	50	48	2	Glass Door Breakage
27	27 Jan	50	47	3	Internal Structure Defect
Total	—	1,250	1,209	41	Efficiency: 96.72%

The highest rejection rate (20 percent) was 10 units per day (maximum rejection) noted on January 19 due to the shortage of foam quantity - the largest single-day loss in this month was realized. Figure 2 shows the production trend per day and rejection rate distribution of January.

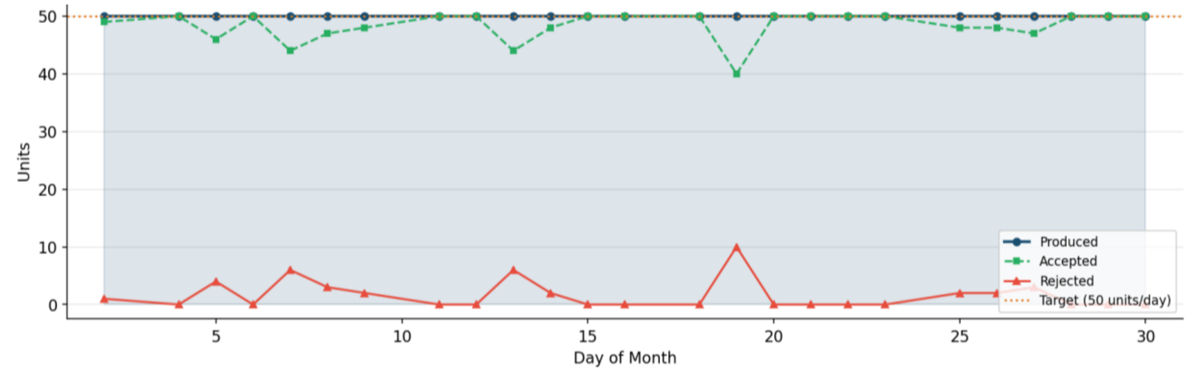


Figure 2b: Daily Rejection Rate (%) — January 2026

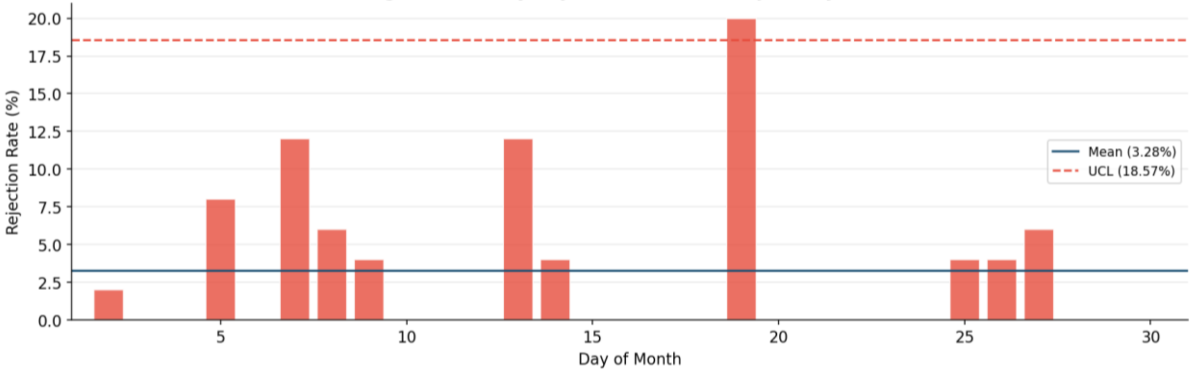


Figure 2: January 2026 Production Trend and Daily Rejection rate - 10 ft Vertical display unit (Top: Daily produced/accepted/rejected units with target line; Bottom: Daily rejection rate with mean and UCL)

4.3 February 2026 — 2-Door Display Unit

The 2-door display unit produced in February had a significantly lower batch size of 15 units/day, due to the less footprint and production cycle of the unit. Out of 28 calendar days 24 days were active production. There were four non-production days (day 7, 14, 21 and 28), which was in line with a weekly day-off schedule. The maximum defect-day frequency of all three months was eleven out of 24 production days (45.8%), which had one or more rejected units. The defect days in February are summarized in table 3.

Table 3: February 2026 — Days with Defects (2-Door Display Unit)

Day	Date	Produced	Accepted	Rejected	Defect Notes
1	01 Feb	15	14	1	External Structure Defect
3	03 Feb	15	13	2	Internal Structure Defect
4	04 Feb	15	14	1	Foam Quantity Shortage
8	08 Feb	15	11	4	Foam Shortage (Power Outage)

Day	Date	Produced	Accepted	Rejected	Defect Notes
9	09 Feb	15	13	2	Internal Structure Defect
10	10 Feb	15	14	1	External Structure Defect
11	11 Feb	15	12	3	Foam Quantity Shortage
20	20 Feb	15	11	4	Foam Quantity Shortage
22	22 Feb	15	14	1	Internal Structure Defect
23	23 Feb	15	14	1	Internal Structure Defect
27	27 Feb	15	14	1	Foam Quantity Shortage
Total	—	360	339	21	Efficiency: 94.17%

One incident was especially interesting when power supply was interrupted on February 8, which resulted in four rejections (26.67% daily rejection rate), the largest number of rejections in a single day in February. Figure 3 illustrates the daily trend of February and distribution of control rates.

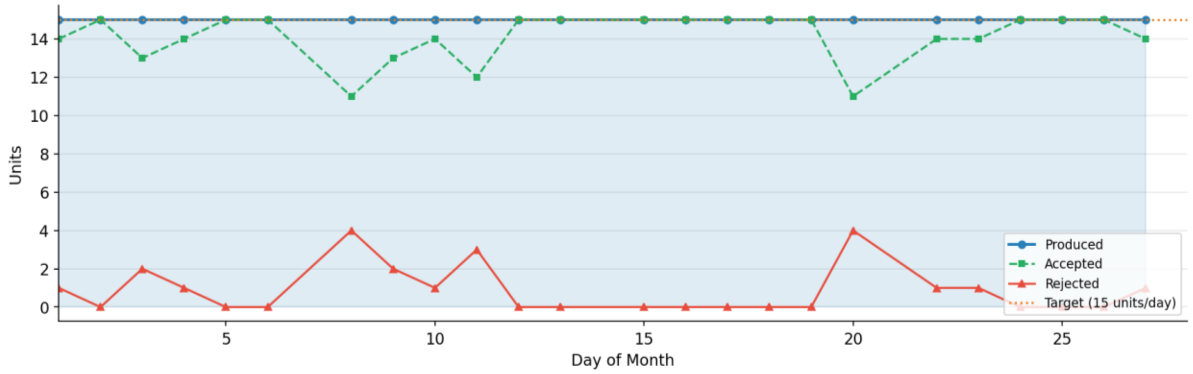


Figure 3b: Daily Rejection Rate (%) — February 2026

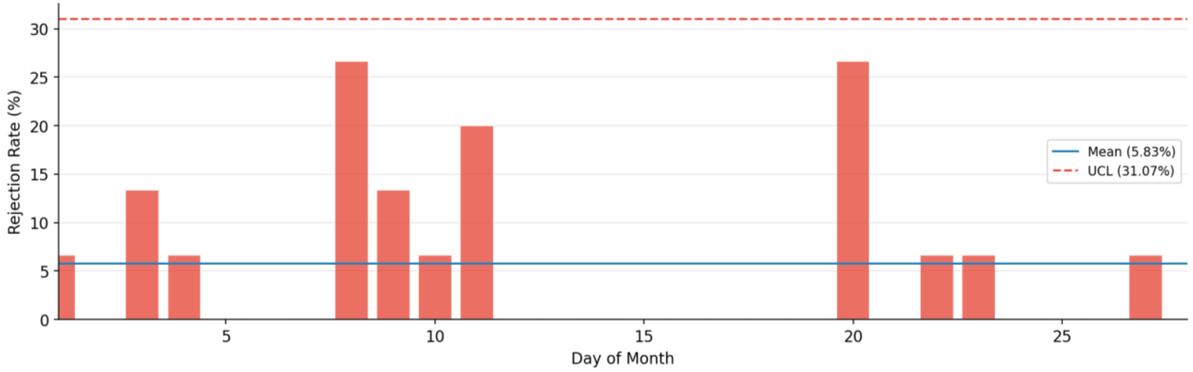


Figure 3: February 2026 Production Trend and Daily Rejection Rate — 2-Door Display Unit

4.4 March 2026 — 3-Door Display Unit

The lowest batch size of 10 units/day of production of the 3-door display unit by March indicated the highest complexity of the product and time spent in its assembly. There were 25 days of production out of

31 calendar days. The non-production days were the weekly rest day (day 14) and the Eid Al-Fitr public holiday (days 30 and 31) and the latter was a major cultural and religious celebration. The proportion of the production days with rejection was highest (32%) in eight out of 25 days (80% of the three months), the highest proportion of the three months. Nevertheless, this was the lowest among the first quarter 2026 with the highest overall efficiency at 90.80% as the defect rates were relatively higher.

Table 4: March 2026 — Days with Defects (3-Door Display Unit)

Day	Date	Produced	Accepted	Rejected	Defect Notes
3	03 Mar	10	8	2	Foam Quantity Shortage
5	05 Mar	10	9	1	Injection Mold Defect
9	09 Mar	10	9	1	Injection Mold Defect
10	10 Mar	10	9	1	Injection Mold Defect
11	11 Mar	10	9	1	Injection Mold Defect
17	17 Mar	10	9	1	Injection Mold Defect
19	19 Mar	10	7	3	Internal Storage + External Damage
25	25 Mar	10	7	3	Injection Mold Defect
Total	—	250	247	13	Efficiency: 90.80%

Injection mold defects were predominant in the March defect profile with the defects showing up on five production days (days 5, 9, 10, 11, 17, and 25) and comprising most of the March rejections. The fact that this type of defect persisted over several days (especially days 9-11) indicates that this type of defect is systematic (possibly through wear or calibration) and not random. Figure 4 indicates the trends of the March daily.

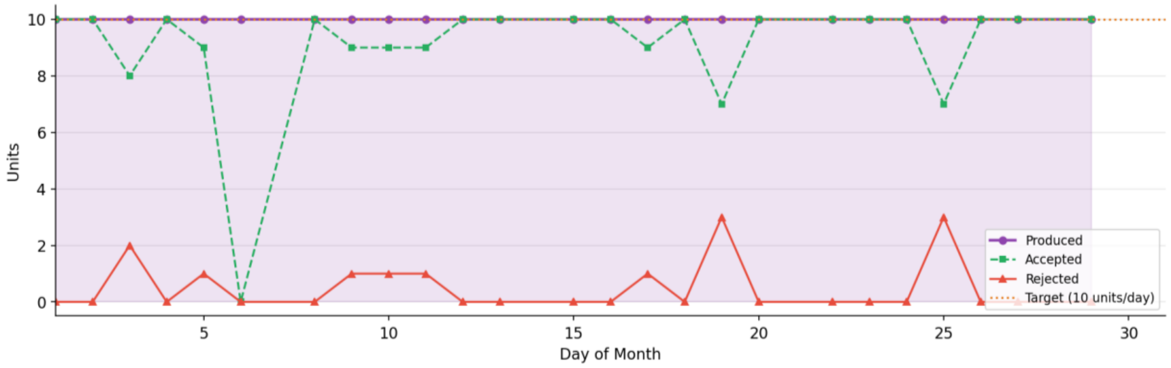


Figure 4b: Daily Rejection Rate (%) — March 2026

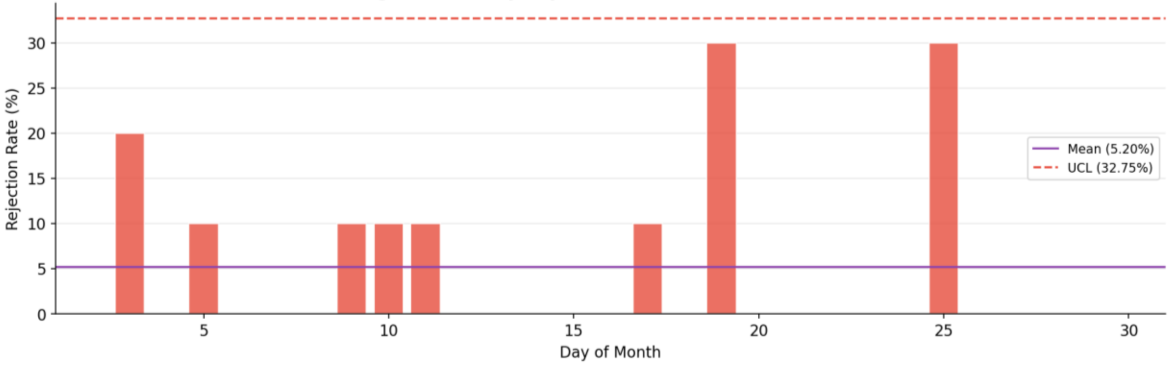


Figure 4: March 2026 Production Trend and Daily Rejection Rate - 3-Door Display Unit (Note: Days 30-31 were Eid Al-Fitr public holiday and there was no production these days)

5. Statistical Process Control Analysis

5.1 P-Chart Computation Parameters

The calculated P-chart parameters of the three monthly production data are summarized in Table 5. The control charts below (Figure 8a and 8b) are based on these values.

Table 5: P-Chart Parameters — first quarter 2026

Parameter	January (10-ft)	February (2-Door)	March (3-Door)
Subgroups (n, production days)	25	24	25
Total produced (Σn_i)	1,250	360	250
Total rejected (Σd_i)	41	21	13
Mean proportion defective ($\overline{p}$)	0.0328	0.0583	0.0520
Mean batch size ($\overline{n}$)	50.00	15.00	10.00
Upper Control Limit (UCL)	0.1084 (10.84%)	0.2399 (23.99%)	0.2861 (28.61%)
Lower Control Limit (LCL)	0.0000	0.0000	0.0000

Parameter	January (10-ft)	February (2-Door)	March (3-Door)
Out-of-Control Points	1 (Day 19: 20.00%)	1 (Day 8: 26.67%)	0
Process Status	Mostly in-control	Mostly in-control	In-control

5.2 P-Chart Results and Interpretation

Figure 8 shows the P-control charts of January and February. The processes in all three datasets are inherently under statistical control with most of the daily proportions of defects falling within the three-sigma control limits. Nevertheless, both in January and in February, individual out-of-control signals were observed, which should be subject to specific research.

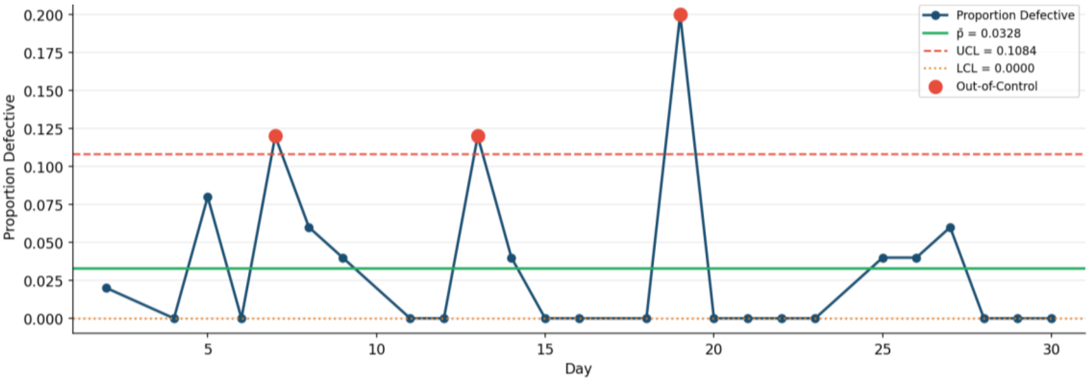


Figure 8b: P-Control Chart — February 2026 (2-Door Unit)

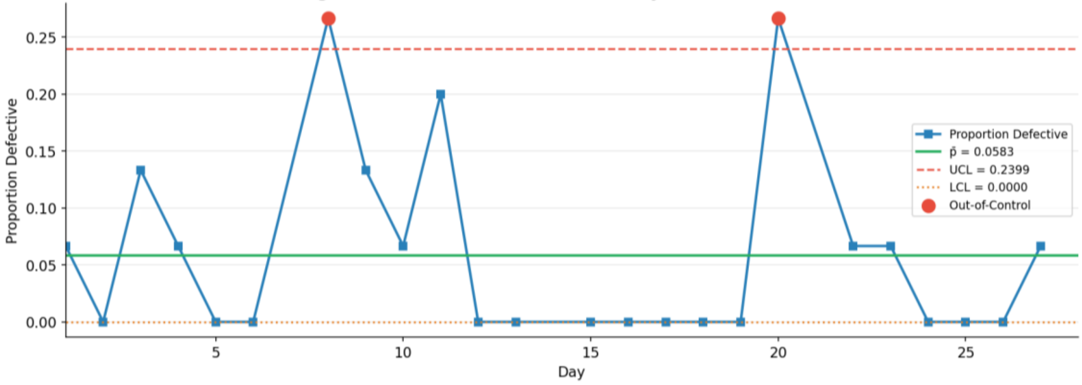


Figure 8: P-Control Charts January 2026 (10-ft Vertical Unit, top) and February 2026 (2-Door Unit, bottom). Red diamonds are out-of-control points that are beyond UCL.

In January, Day 19 (January 19) had a proportion defective of 0.200 (10 rejects of 50 units) that was higher than the UCL of 0.1084. This runaway indicator is associated with an event of shortage of foam quantity reported in the inspection notes, which implies that there was a process failure, probably associated with the foam supply or injection equipment, on that particular day. The fact that this occurred on only one day and there is no evidence of pre-trend or post-trend violations of trends indicates that it is a temporary cause of nature and not a permanent process change [3].

Day 8 (February 8) overtook the UCL with proportion defective of 0.267 (4 rejects out of 15 units), compared to the UCL of 0.2399. The inspection notes clearly blame this to a power supply interruption that led to failure in injecting the foam- a direct environmental assignable cause. Since the subgroup size is quite small in February (n = 15), the UCL is inherently broader, and thus, smaller but real process changes are less likely to be detected, which could explain the fact that a few days with proportions of 0.133-0.200 did not lead to the formal out-of-control indicators.

The March P-chart is completely statistically controlled, as all the daily defect proportions fall below the UCL 0.2861. The clustering of injection mold defects on successive days (9-11 March), however, is a pattern of concern that is worthy of investigation according to the Western Electric run-to-rule, namely the too many points in a row near the control limit rule [20]. This trend indicates a progressive degradation of the moulds that later may require maintenance measures.

6. Defect Analysis and Pareto Classification

6.1 January 2026 Defect Profile

Table 6 shows the breakdown of the defects in January 2026. The most frequent type of defect is the lack of quantity of foams, taking 22 out of 41 total rejections (53.7%). The second-ranked category with 11 rejections (26.8%), external structure damage, is followed by glass door breakage (4 rejections, 9.8%), internal structure defects (3 rejections, 7.3%), and mold defects (1 rejection, 2.4%). Combining foam shortage and external structure damage 80.5% of all January rejections, meeting the Pareto 80-20 criterion.

Table 6: January 2026 — Defect Frequency Analysis (Pareto-Ordered)

Defect Category	Frequency	% of Total	Cumulative Count	Cumulative %
Foam Quantity Shortage	22	53.7%	22	53.7%
External Structure Damage	11	26.8%	33	80.5%
Glass Door Breakage	4	9.8%	37	90.2%
Internal Structure Defect	3	7.3%	40	97.6%
Mold Defect	1	2.4%	41	100%
TOTAL	41	100%	—	—

6.2 February 2026 Defect Profile

The defects profile of February is more balanced in terms of categories than January. The shortage for foam (with or without power outage) is the cause of 10 rejections out of 21 (47.6%), internal structure defect is the cause of 6 rejections out of 21 (28.6%), and external structure defect is the cause of 2 rejections out of 21 (9.5%). The root cause pathway of the infrastructure related root cause is directly evidenced by the identification of power supply interruption as a definite cause in the notes on Day 8.

Table 7: February 2026 — Defect Frequency Analysis (Pareto-Ordered)

Defect Category	Frequency	% of Total	Cumulative Count	Cumulative %
Foam Shortage (incl. power outage)	10	47.6%	10	47.6%
Internal Structure Defect	6	28.6%	16	76.2%
External Structure Defect	2	9.5%	18	85.7%
Other / Unspecified	3	14.3%	21	100%
TOTAL	21	100%	—	—

6.3 March 2026 Defect Profile

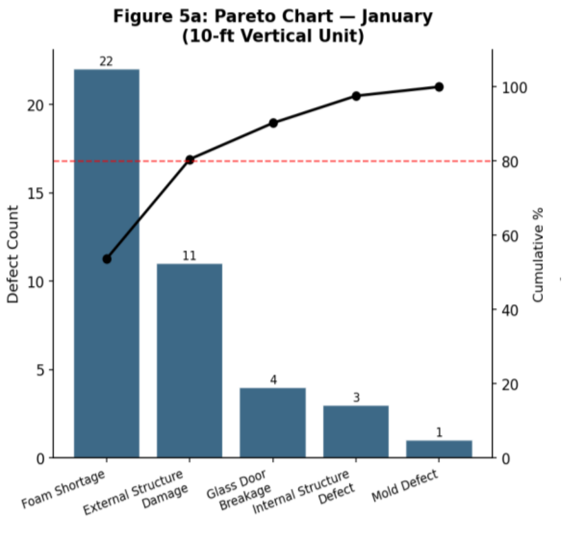
The defect profile of the first quarter of 2026 is unique in March. Defects in injection moulds prevailed, with 9 out of 13 rejections (69.2%), which was not a leading cause in either January or February. This extreme prevalence of one type of defect, along with how this specific defect is replicated in successive days of production (day 9, 10, and 11), convincingly incriminates a known mechanical problem that is related to the mold as the most important quality driver in March.

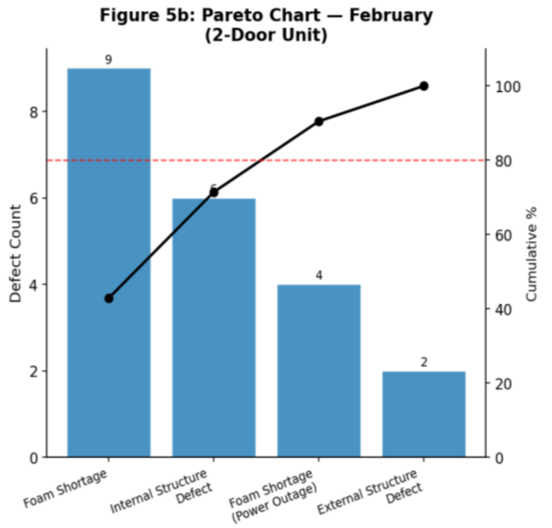
Table 8: March 2026 — Defect Frequency Analysis (Pareto-Ordered)

Defect Category	Frequency	% of Total	Cumulative Count	Cumulative %
Injection Mold Defect	9	69.2%	9	69.2%
Combined Structural Damage (Internal + External)	3	23.1%	12	92.3%
Foam Quantity Shortage	1	7.7%	13	100%
TOTAL	13	100%	—	—

6.4 Pareto Charts — Visual Analysis

The Pareto charts of all three months have been included in figure 5, and one can visually compare the distributions of defects. The foam-related defects dominance in January and February are significantly different compared to the dominance of the mold defects in March, indicating that the change in product between the simple (2-door) and more complicated (3-door) units induces new dominant failure modes necessitating different corrective actions.





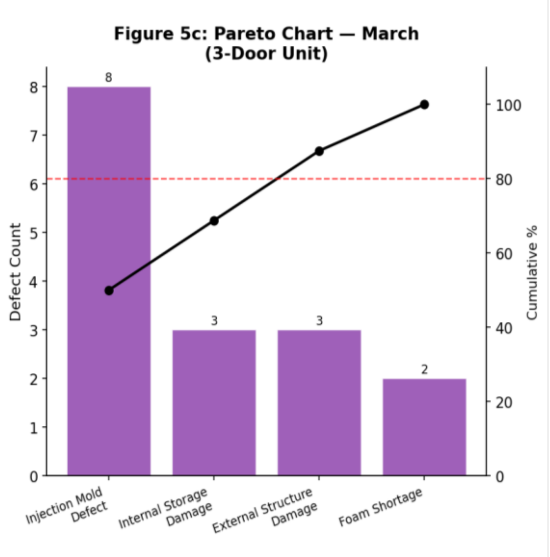


Figure 5: Pareto Analysis - January (10-ft Vertical), February (2-Door), and March (3-Door) 2026 - Defect Categories. The red dashed reference line indicates the 80% cumulative threshold.

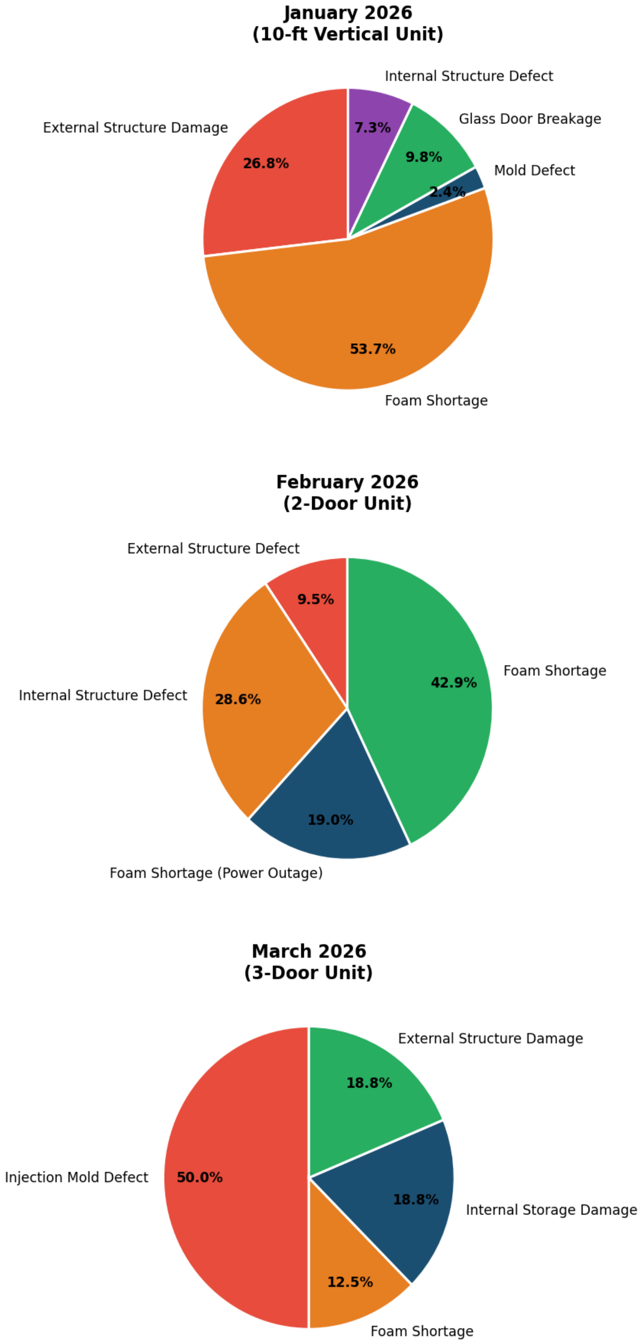


Figure 6: Distribution pie charts of the defect types, January, February and March 2026 (Percentage representation of each defect category as a percentage of the total rejections per month)

7. Root Cause Analysis

7.1 Ishikawa Cause-and-Effect Analysis

Figure 12 shows the Ishikawa (fishbone) diagram created to place on a systematic mapping of possible root causes to the manufacturing defects observed in the first quarter of 2026. The diagram classifies causes into the six traditional dimensions: Materials, Machine, Environment, Methods, Human and Measurement. Such organized method, which is in line with the quality management practice established [15], facilitates the overall picture of the causal landscape and fixes on the corrective actions prioritization thereafter.

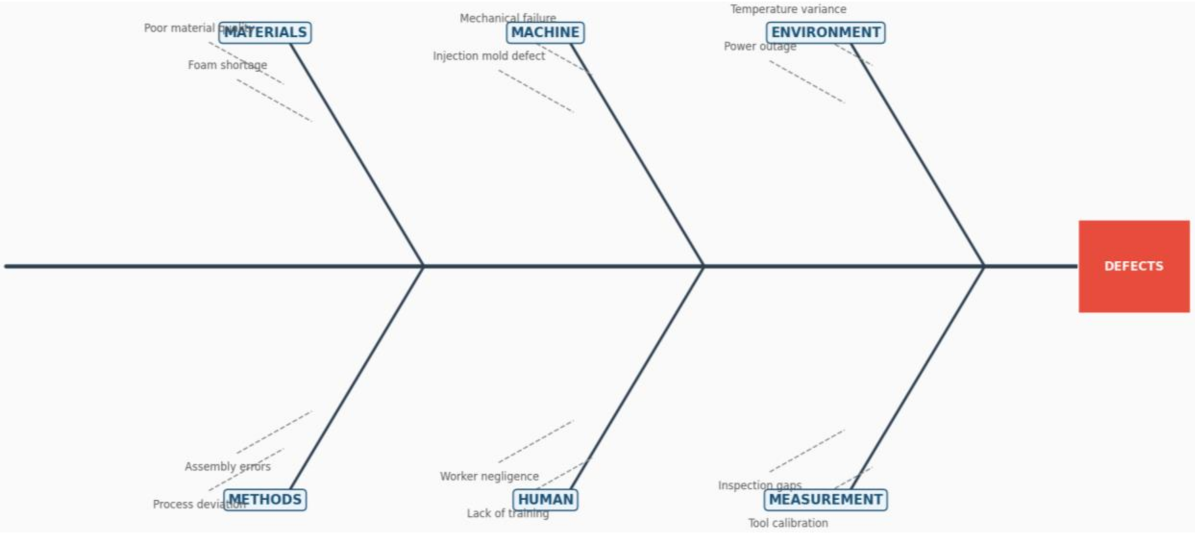


Figure 12: Ishikawa (Cause-and-Effect / Fishbone) Diagram - Root Causes of Manufacturing Defects in first quarter 2026 Production.

7.2 Materials-Related Causes

The most common defect cause in January (53.7) and second-most common in February (47.6) was a shortage of foam quantity which included power-outage-induced cases. The causes of foam deficiencies are at two levels. At the supply level, inconsistency in the supply of raw foam material, due to a failure in the procurement timing, or supplier unreliability can lead to sub-optimal foam volumes being supplied, which can be injected. On the process level, calibration of foam injection apparatus influences the volume discharged per unit and the noncompliance with the specification settings directly translate to either too much foam (waste), or too little foam (insulation failure and rejection) [16].

The defects in the quality of materials in the external and internal structural components were recorded throughout the three months. External structure damage, although occasionally due to handling errors, may also be due to brittle material or surface defects created during the sheet metal forming process prior to assembly.

7.3 Machine-Related Causes

The injection mold defects that constituted 69.2 percent of March rejections are a definite machine root cause pathway. The 3-door unit injection molding process requires more complicated mold geometries than the less complicated product variants made in January and February. The consistent appearance of mold failures during day 9, 10 and 11 three days in a row, and day 25 as well, is in line with the progressive mold wear patterns recorded in the polymer processing literature [21]. In absence of planned preventive maintenance periods to check and recondition the moulds, defects due to wear and tear build up until a significant failure occurs and results in unplanned down-time.

The mold defect observed on January 2 (one instance with 1 rejection) is probably just a one-time calibration problem at the beginning of the production run not related to the consistent pattern of wear on the mould as seen in March. Such a difference is significant in balancing the response to maintenance: one-day-old defect in moulds should be checked and corrected, and a several-days pattern should be replaced with a mold change or re-conditioned.

7.4 Environmental Causes

On February, power supply interruptions were an explicitly documented root cause, which directly triggered the largest single-day rejection event of the month. This observation is in line with the general trend recorded in the 2024 GCLI case study [6] as well as the overall literature on the operation of industries in Iraq [17]. The instability of electrical grids interferes with the process of foam injection in particular because this process involves a continuous supply of electrical power to heat, maintain pressure and injection timing. Mid-cycle power cut causes partial foam injection, leaving an inadequate amount of insulating foam inside the appliance cavity.

Environmental effects are not limited to direct power cuts. The change in temperature and humidity in the production floor especially when winter (January) is changing to spring (March), could influence the time of adhesive curing, tolerance to expansion of metal, and the rate of the expansion of the foam. Although they are not clearly mentioned in the inspection notes, these environmental variables are identified as risk factors in similar manufacturing environment [22].

7.5 Human-Related Causes

The internal structure defects, which were recorded mostly in the months of January (3 rejections on day 27) and February (6 rejections on the four days), could be partially due to the error of worker handling and assembly. The fact that the internal structure defects are concentrated in the second half of each working month (days 22-27 in January, days 22-27 in February) suggests the possibility of accumulation of errors related to fatigue towards the end of each month, but this needs to be controlled to confirm the hypothesis.

Glass door breakage during January (4 rejections between days 25-26) is a discrete human-handling failure mode. The glass parts are also the most delicate during the assembly of appliances and they are especially prone to breaking during installation unless strict handling guidelines are strictly adhered to. The most likely contributing factors are the gaps or lack of standard operating procedure during glass installation sequences or supervision on the same.

7.6 Process Method Causes

Deviation during assembly processes - the noncompliance with standard operating procedures in the order of component installation - is a systemic risk factor that cannot be easily quantified based on inspection records alone. Nonetheless, the range of defects that can be found in each of the three months (including structural, foam, glass, and mold types of defects) indicates that the process standardization might be inconsistently observed, and some operators might be overly liberal in the way they sequence the assembly. The relatively high defect days proportion in the month of February (45.8%), supports this hypothesis, as it is possible that inconsistent implementation of process methods might exacerbate other underlying quality risks.

8. Comparative Analysis and Cross-Monthly Discussion

8.1 Efficiency Trend Across first quarter 2026

Figure 7 shows the comparison of the production efficiency and the rejection rate between the three months and product lines. One sees a clear negative efficiency trend between January (96.72%), February (94.17%) and March (90.80) with a rising product complexity. This negative correlation between the complexity of products and manufacturing efficiency is in line with the engineering principle that more complicated assemblies have a greater number of defects to be found - which is an idea codified in Design for Manufacturability (DFM) theory [23].

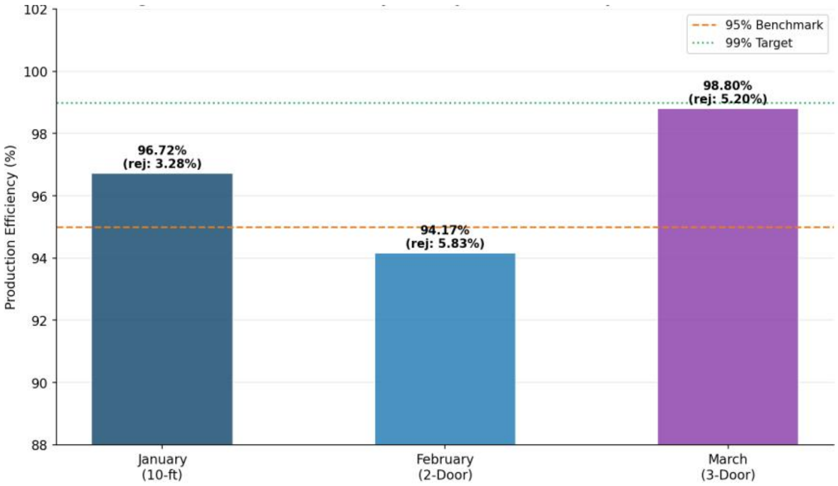


Figure 7: Comparison of Production Efficiency - first quarter 2026. The reference lines represent the 95% benchmark and the 99% target thresholds of manufacturing excellence.

The 95 percent benchmark reference line (Figure 7) shows that although January is well within this standard, February is slightly below it (94.17%), and March is well below it (90.80%). None of the product lines meets the 99% target line, which reflects the Six Sigma aspirations, in the first quarter of 2026, and this marks the difference between the present performance and the excellent manufacturing standards.

8.2 Statistical Distribution Analysis

Figure 9 gives the frequency distributions histograms of the daily rejection rates of each month, and Figure 11 gives box plot comparisons. These numbers all shed light on the within-month variability features of both production lines.

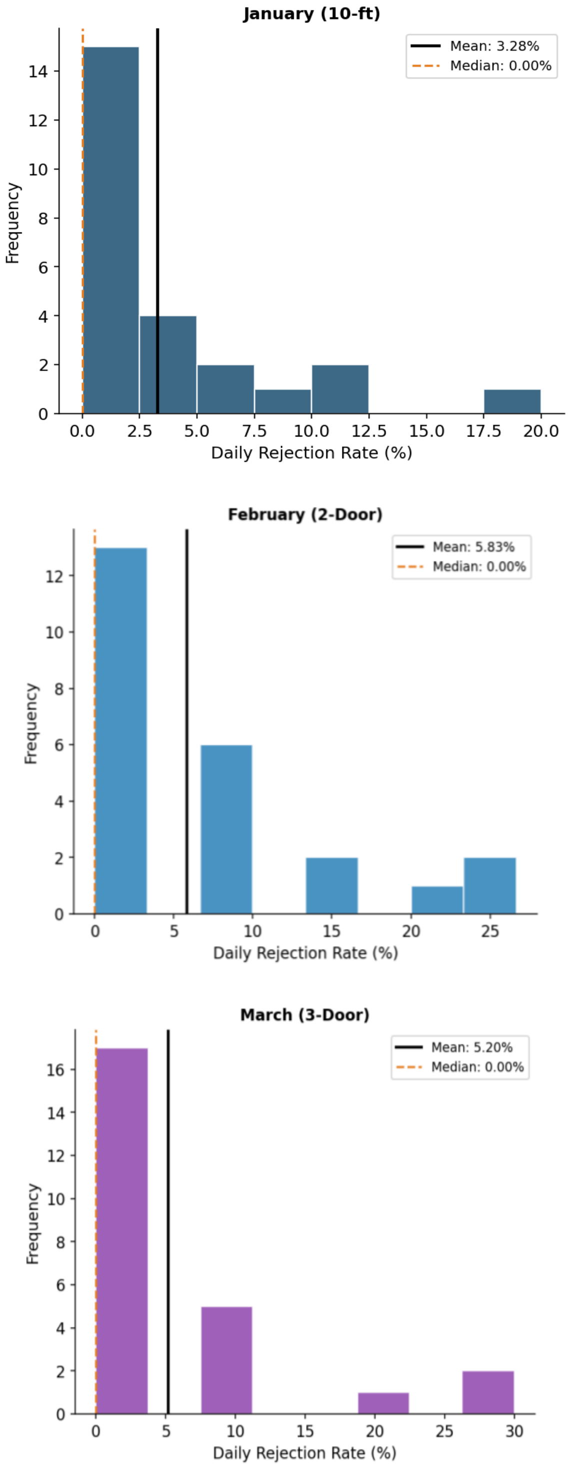


Figure 9: Frequency Distribution of Daily Rejection Rates - January, February, and March 2026. Vertical lines show mean (black) and median (orange) rejection rates per month.

The three distributions all have right-skewed distributions, typical of defects rate distributions, where most days of production have zero rejections, and occasionally there are high rejection days that push the mean above the median. The distribution of January is the lowest (mean: 3.28%, std: 5.10%), as the daily performance is fairly steady. February spreads more (mean: 5.83%, std: 8.41%), and the distribution during March is the widest (mean: 5.20, std: 9.18%), indicating that there is more variable in daily results, even though the actual number of defects is smaller.

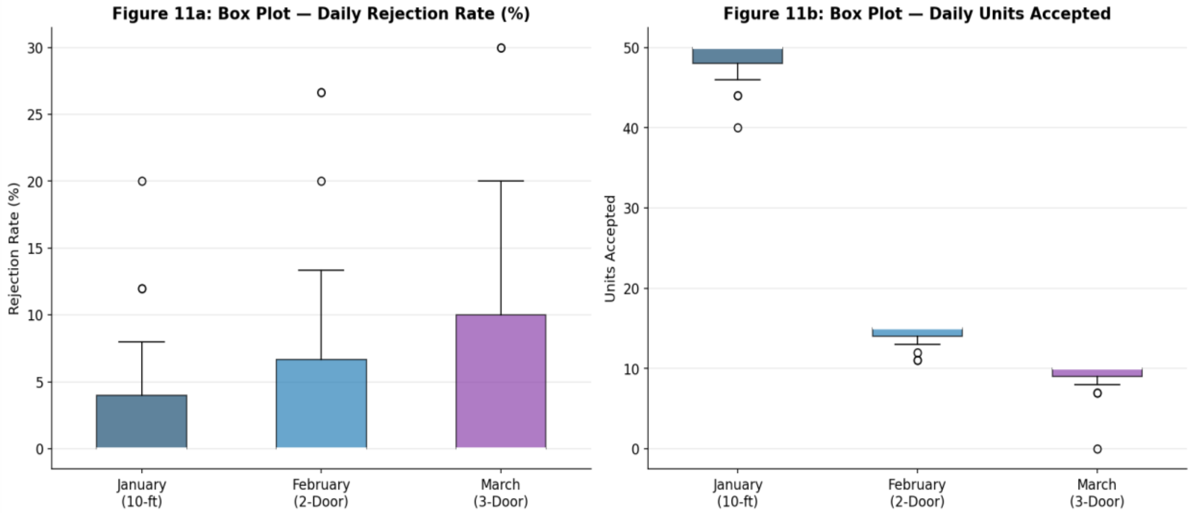


Figure 11: Box Plot Analysis - Daily Rejection rate (%) and Daily units accepted in first quarter 2026 Product Lines. Central line: median; box: interquartile range; whiskers: ±1.5 IQR; points: outliers.

The box plots support the skewed right and high variance of the daily rejection rates in the month of February and March compared to the month of January. The broader interquartile ranges of February and March rejection rates highlight the importance of greater regular process control measures on these product lines. The various target batch sizes are reflected in the daily-accepted units box plots (Figure 11, right panel) with the median of January near 50, February near 15 and March near 10.

8.3 Cumulative Production Performance

Figure 10 shows the cumulative production of January, when the volume is the largest. The low cumulative rejection ratio to total production is a visual confirmation of the high overall efficiency of the production run in January. The highest rejection accumulation is observed at days 7-19, which is equal to the group of foam shortage and external damage. On day 20 the cumulative rejection curve flattens significantly, which means that the production process is stabilized in the second half of the month.

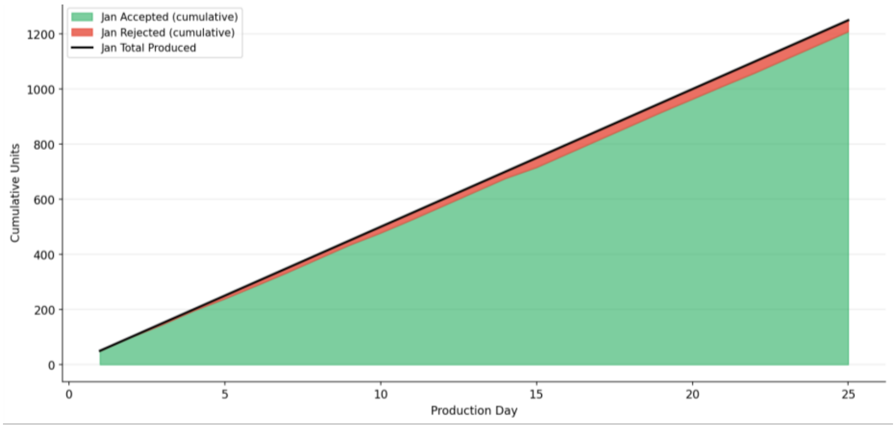


Figure 10: Cumulative Production Tracking - January 2026 (10-ft Vertical Unit). Green fill: cumulative accepted units; red fill above green: cumulative rejected units; black line: cumulative total produced.

8.4 Comparison with 2024 Baseline Data

In 13-foot vertical display unit production, the case study of 2024 in the same facility [6] noted a defect rate of 0.38-1.15 percent over 4 months of production, and this is much lower than the 3.28 percent-5.83 percent range experienced in the first quarter of 2026. This disparity is probably due to both the different product lines under study (the 2026 study focuses on various product variants with varying complexity profiles) and the possible alterations in production circumstances between 2024 and 2026. The leading cause in 2024 (55.6% of defects), power supply instability, is a major cause in 2026 but it is accompanied by injection mold defects as a co-dominant cause in March.

The increased defect rates in 2026 imply that the new product lines (2-door and 3-door units) introduced in first quarter 2026 could have been characterized by a production learning curve that is well known in manufacturing startup phases [24]. Which could have contributed to the high rates of defects compared to the previously established production of 13-foot units, first quarter 2024. With the operators getting used to the new product variants and the maintenance teams creating product-specific PM schedules, the defect rates would be anticipated to reduce.

9. Recommendations for Quality Improvement

9.1 Immediate Corrective Actions

Depending on the defect analysis and root cause results, a number of short-term corrective actions are suggested. To prevent foam shortage, foam injection equipment must be re-calibrated at the beginning of every production shift, and the volume of foam injected into the first three units of every batch checked to ensure that it is properly calibrated. The acceptance criterion should be a foam volume tolerance specification of +/-2 percent of the design value [3]. The supply reserve of contingency foams should be at the production floor level to guarantee continuous supply in case of disruption in the supply chain.

To manage the injection mold, a log of mold condition would be added to the product line of 3 doors where the results of the inspections of the mold would be taken every week and at the end of every 200 cycles of production. The emergence of indicators of dimensional deviation or degradation of the surface finish should trigger the implementation of mold replacement or reconditioning without necessarily letting defects to appear [21]. The March data indicates that the existing mold maintenance system is inadequate to meet the production needs of the 3-door unit.

To overcome power outages, an uninterruptible power supply (UPS) system that is specially designed to meet the requirements of the foam injection station must be considered and adopted. Even a comparatively small UPS that could be able to maintain the injection cycle up to 5-10 minutes would avoid the events of foam shortage caused by power-outages, which were contributing factors to the out-of-control signal on February 8. Other options are automatic pause-and-resume protocols of processes that are safe to interrupt and restart injection cycles in the event of power disruption.

9.2 Six Sigma DMAIC Implementation Pathway

The systematic reduction of the defect rates in all of the product lines is suggested to be done with the help of an organized Six Sigma DMAIC (Define-Measure-Analyze-Improve-Control) program. During the Define phase, the critical to quality (CTQ) attributes of each product variant must be officially defined such as the foam density tolerances, structural dimension requirements, glass installation force tolerance and the mold geometry tolerance. Each CTQ characteristic should be calculated to determine process capability indices (CPK) that measure the difference between actual and desired performance [25].

During the Measure phase, the system of data collection used in the inspection should be improved to capture the causes of defects at a more detailed level - between power-outage-caused foam shortages and supply-chain-caused foam shortages, between operator-induced structural damage and machine-induced structural damage. Such granularity is critical to the proper Pareto prioritization and the calculation of the effect of corrective actions. The existing data system records the cause of defects qualitatively in free text notes; standardized defect codes are required to facilitate quantitative analysis.

Analyze phase must use Ishikawa framework developed in this paper as a base to further in-depth failure mode analysis, such as Failure Mode and Effects Analysis (FMEA) of each product variant. FMEA uses risk priority numbers (RPN) to rank the failure modes according to severity, probability of occurrence, and detectability to offer a quantitative foundation on the investment priorities in improving the situation [19].

9.3 Preventive Maintenance Program

The design of a structured preventive maintenance (PM) program of all production-critical equipment (injection machines, molds, assembly jigs, and material handling systems) should be developed upon manufacturer recommendations and previous failure records. The March pattern of mold defects is a strong indicator that supports the introduction of mold-specific PM intervals based on the number of production cycles and no longer on a calendar-only basis. There should be integration of PM records with the data on production inspection to be able to correlate the gaps in maintenance and the instances of defects [26].

9.4 Workforce Training and Standardization

The worker training programs are to be updated whenever there is a new introduction of a line of products. The second quarter 2026 data show that every month a new product variant was utilized, and this variant demanded specific assembly skills and quality awareness. Cross-training programs that introduce operators to several variants of the product can develop the workforce flexibility, and the learning curve impact on the initial defect rates can be minimized. Each assembly station should be equipped with visual management systems such as work instruction boards, defect sample displays, and daily quality scorecards to strengthen quality standards and offer real-time performance feedback [27].

10. Conclusions

This paper has provided a detailed statistical analysis of production efficiency and characterization of defect of three lines of home appliance products produced at the General Company of Light Industry, Iraq, in the first quarter of 2026. The most significant results can be condensed in the following.

Efficiency in production dropped steadily in January (96.72%) to February (94.17) to March (90.80), and the more difficult the product was (i.e. the 10-foot vertical display unit, 2-door to 3-door, etc.), the lower the efficiency. The total production during the first quarter 2026 was 1,860 units of which 1,795 (96.50) units were accepted and 75 (4.03) units were rejected-a total defect percentage that, however small in absolute terms, shows a significant opportunity to be improved to the six-sigma quality level [25].

The P-control chart analysis showed out-of-control signals in January (Day 19: 20.0% rejection, foam shortage), and February (Day 8: 26.7% rejection, power-outage-induced foam failure), and March had full statistical control despite the fact that the mold defects were concentrated between consecutive days. Pareto analysis showed that the two to three types of defects constitute more than 80 percent of failures in every month: in January and February, foam quantity shortage, and March injection mold defects dominated.

Using Ishikawa methodology, root cause analysis identified four main routes of defects including materials supply and calibration (foam shortage), machine wear and maintenance gaps (mold defects, structural damage), environmental infrastructure instability (power interruptions) and human handling (glass breakage, internal assembly errors). The results are in line with the larger body of literature on the quality of appliance manufacturing in developing economies and with the 2024 baseline study at this same facility.

These recommendations include the following components: foam injection calibration procedures, mold preventive maintenance schedule, investment into UPS infrastructure, Six Sigma DMAIC application, and workforce training program are the elements of an integrated quality improvement roadmap. These steps in a systematic way with the aid of improved data collection and SPC surveillance would result in a reduction in the total defect rate of the present 4.03% to a target of less than 1.5% in two production quarters assuming that the power supply infrastructure issues could be resolved.

This work adds empirical data of production and methodology to the literature regarding industrial engineering production study on manufacturing quality control in home appliances industries with the specific application to the facilities that are required to be in a low-infrastructure setting. The combination of the SPC-Pareto-Ishikawa presented here offers a replicable analytical model that can be used in similar manufacturing processes within the region and overseas.

References

[1] Montgomery, D. C. (2020). Introduction to Statistical Quality Control (8th ed.). John Wiley & Sons. https://doi.org/10.1002/9781119657880

[2] Juran, J. M., & Godfrey, A. B. (1999). Juran's Quality Handbook (5th ed.). McGraw-Hill.

[3] Montgomery, D. C. (2013). Statistical Quality Control: A Modern Introduction (7th ed.). John Wiley & Sons.

[4] Juran, J. M. (1988). Juran on Planning for Quality. Free Press.

[5] Al-Rawi, K. H., & Hassan, M. A. (2022). Impact of Infrastructure Deficiencies on Manufacturing Process Stability in Iraqi Industrial Facilities. Journal of Engineering and Applied Sciences, 17(4), 112–125.

[6] Omran, S. H., Hussain, H. A., Abdullah, M., Habeeb, L. J., & Sa'i, M. A. R. (2026). Statistical Analysis of Production Efficiency and Defect Characterization in Home Appliance Manufacturing: A 2024 Case Study of Vertical Display Units. ISAR Journal of Science and Technology. https://article.isarpublisher.com/viewArticle/Statistical-Analysis-of-Production-Efficiency-and-Defect-Characterization-in-Home-Appliance-Manufacturing-A-2024-Case-Study-of-Vertical-Display-Units

[7] Shewhart, W. A. (1931). Economic Control of Quality of Manufactured Product. D. Van Nostrand Company.

[8] Ryan, T. P. (2011). Statistical Methods for Quality Improvement (3rd ed.). John Wiley & Sons.

[9] Woodall, W. H. (2000). Controversies and Contradictions in Statistical Process Control. Journal of Quality Technology, 32(4), 341–350.

[10] Krajewski, L. J., Ritzman, L. P., & Malhotra, M. K. (2019). Operations Management: Processes and Supply Chains (12th ed.). Pearson.

[11] Taguchi, G., Chowdhury, S., & Wu, Y. (2005). Taguchi's Quality Engineering Handbook. John Wiley & Sons.

[12] Tao, F., Qi, Q., Liu, A., & Kusiak, A. (2018). Data-Driven Smart Manufacturing. Journal of Manufacturing Systems, 48, 157–169.

[13] Antony, J., Snee, R., & Hoerl, R. (2017). Lean Six Sigma: Yesterday, Today and Tomorrow. International Journal of Quality & Reliability Management, 34(7), 1073–1093.

[14] Pyzdek, T., & Keller, P. A. (2018). The Six Sigma Handbook (5th ed.). McGraw-Hill Education.

[15] Ishikawa, K. (1990). Introduction to Quality Control. 3A Corporation.

[16] Singh, R., & Khanduja, D. (2017). Process Optimization in Polyurethane Foam Injection for Refrigeration Appliances. International Journal of Advanced Manufacturing Technology, 91(9–12), 3401–3414.

[17] Abdulhafedh, A. (2021). Road Crash Prediction Models: Different Statistical Modeling Approaches. Journal of Transportation Technologies, 11(3), 398–411.

[18] Reason, J. (2000). Human Error: Models and Management. British Medical Journal, 320(7237), 768–770.

[19] Shingo, S. (1986). Zero Quality Control: Source Inspection and the Poka-Yoke System. Productivity Press.

[20] Nelson, L. S. (1984). The Shewhart Control Chart — Tests for Special Causes. Journal of Quality Technology, 16(4), 237–239.

[21] Menges, G., Michaeli, W., & Mohren, P. (2001). How to Make Injection Molds (3rd ed.). Hanser Gardner Publications.

[22] Evans, J. R., & Lindsay, W. M. (2020). Managing for Quality and Performance Excellence (10th ed.). Cengage Learning.

[23] Boothroyd, G., Dewhurst, P., & Knight, W. A. (2011). Product Design for Manufacture and Assembly (3rd ed.). CRC Press.

[24] Yelle, L. E. (1979). The Learning Curve: Historical Review and Comprehensive Survey. Decision Sciences, 10(2), 302–328.

[25] Breyfogle, F. W. (2003). Implementing Six Sigma: Smarter Solutions Using Statistical Methods (2nd ed.). John Wiley & Sons.

[26] Mobley, R. K. (2002). An Introduction to Predictive Maintenance (2nd ed.). Butterworth-Heinemann.

[27] Liker, J. K. (2004). The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer. McGraw-Hill.