Improvement of Overall Efficiency (UPH) of Assembly Production Line in Refrigerator Factory through Time Study and Kaizen-Based Line Balancing: A Case Study from Pakistan's Appliance Industry

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Importance of Study: The following reasons explain why the study was conducted at local facilities: Unbalanced workstations and undocumented work procedures prevent many local facilities from operating at the desired level. The present study examines the general assembly line of the largest refrigerator manufacturing plant in Pakistan, which is currently operating at 80 units per hour (UPH) against a designed capacity of 120 UPH.
Novelty Statement: The study combines time study, Kaizen, line balancing, and manpower optimization into a single statistically validated model, which is rarely reported in the literature, particularly in the context of the appliance industry in Pakistan, using a real factory case.
Material and Method: The structured methodology adopted for improvement included detailed time study, bottleneck diagnosis using Yamazumi charts, station redesign based on Kaizen, line balancing, ergonomic interventions, and manpower reallocation across all 67 workstations.
Result & Discussion: Seven bottleneck stations were identified, with cycle times of 41–43 seconds, all exceeding the takt time of 28.125 seconds. Six stations were reduced to 27-28 seconds (or less) by Kaizen interventions. Station S44 (Helium Recovery) was reduced from 43 seconds to 29 seconds, just slightly above the takt time because of the minimum cycle time of the equipment, however, the ability to do parallel processing at S44 allowed the throughput at that station to be doubled, eliminating it as a station bottleneck. The line throughput increased from 80 UPH to 120 UPH (+50%), with the binding constraint eliminated. A paired t-test was then performed on the cycle times of all 67 stations, and the improvement was found to be statistically significant ($t = 2.785$, $df = 66$, $p = 0.007$). Labour Cost per Unit decreased by 33% (Rs 500 per unit to Rs 333 per unit) and the capacity grew by some 7,800 units per month.
Conclusions: It is seen that the use of time study and Kaizen along with line balancing can be used to overcome the large gaps in the efficiency achieved and the developed model can be used in other high volume assembly lines.

Keywords: Line Balancing; Time Study; Takt Time; Kaizen; Value Stream Mapping; Manpower Allocation

Introduction:

Background and Problem Statement:

Efficiency is a major factor in competitiveness in the appliance industry, which is characterized by high-volume production. The ability to satisfy customer needs for on-time delivery and cost control depends on keeping pace with production. An efficient line is one that balances workstation cycle time with takt time, has a minimum amount of idle time, and a balanced workload between stations [1]. However, many plants still do not systematically adopt time studies and task allocation, which leads to work imbalance, operator fatigue, and low output [2][3].

In this study, the general assembly line of one of the largest refrigerator manufacturing plants in Pakistan was examined. The line comprises 67 sequential workstations manned by over 500 operators and helpers and was designed for 120 units per hour (UPH), but consistently produced 80 UPH. This 40-UPH gap directly led to delayed deliveries, failure to meet customer requirements, and reduced competitiveness. First, it was found that this was not a worker's problem, but rather a problem of too much work to be done in the allotted time at certain stations. These contributing factors were organized with the help of a cause-and-effect (fishbone) diagram which covers the following categories: Man, Machine, Method, Material, Measurement and Environment, prior to beginning the diagnostic time study (see Figure 1).

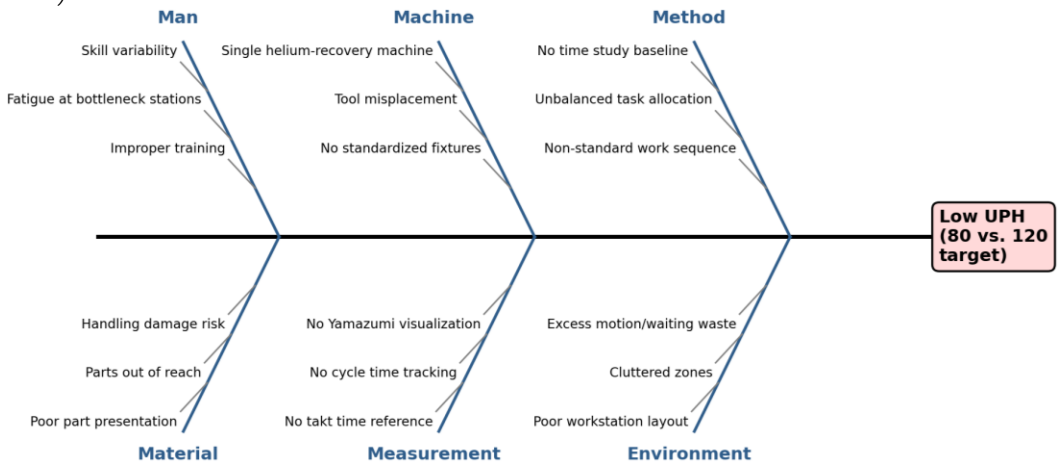


Figure 1. Cause-and-effect (fishbone) diagram — root causes of low UPH (80 units/hour).

Aim and Objectives:

In this study, an attempt is made to increase the overall throughput of the refrigerator assembly line to 120 UPH by systematically applying time study, line balancing, and manpower optimization. Specific goals are to: (i) measure cycle times and identify workstation bottlenecks using detailed time study; (ii) apply line-balancing principles (using Kaizen interventions) to reduce the cycle times of bottleneck workstations and balance workloads across the line; (iii) re-allocate manpower so that no station exceeded 100% of the 28.125-second takt time, targeting a line-balance efficiency of 90% or higher against a pre-intervention baseline of approximately 67%; and (iv) convert the results into practical, low-cost recommendations that can be adopted by other appliance manufacturers.

Significance of the Study:

From an industrial perspective, the research findings provide a practical approach to achieving significant efficiency improvements at low capital expense, without requiring additional floor space or personnel. Academically, the study aims to fill a literature gap, as very little empirical work has been conducted on refrigerator assembly lines in Pakistan compared with the automotive or general manufacturing industries[2][4]. Using the time study, Kaizen, line balancing and statistical validation of the methodology, a real-factory case is used to

provide a methodology and a benchmark for future industrial engineering practice in the region.

Novelty Statement:

There are several novel contributions to the assembly-line optimization literature in this study: (1) Integration — this is one of the first studies to combine time study, Yamazumi-chart diagnosis, Kaizen intervention, line balancing, manpower reallocation, statistical validation, and full-cost/benefit analysis into a single framework applied to a real refrigerator assembly line; (2) Context — empirical case studies in Pakistan's appliance-manufacturing sector are scarce; this paper presents the first statistically validated improvement study covering an entire assembly line in the sector; (3) Bottleneck solution — unlike studies that rely on algorithmic resequencing, physical and ergonomic Kaizen interventions are shown to be more effective when bottlenecks arise from workstation design rather than task precedence; (4) Statistical validity — the paired t-test on all 67 stations (not only on the bottleneck stations) is a more conservative and defensible significance test than is typically reported; and (5) Economic transparency — the full cost-benefit analysis, including the capital cost of the additional helium-recovery machine and its payback period, offers practitioners a realistic investment appraisal template.

Literature Review:

Cycle time, takt time, and output per hour are indicators of assembly-line efficiency. If the cycle time of a station is greater than the takt time, the station becomes a bottleneck and it limits the overall line [5]. Numerous empirical studies have shown that such bottlenecks, when targeted, lead to significant improvements. The study conducted by [6] on a Moroccan automotive plant led them to conclude that lean rebalancing increased the line efficiency from less than 70% to 91% (+21 percentage points) at seven stations, which were all above takt time by 15–42%. [7] performed a review of 15 years of practical line-balancing applications, which indicated that line-balancing implementation can yield efficiency improvements of 15–40%, depending on the initial imbalance. [8] used the Yamazumi-guided simulation rebalancing to a garment line, which resulted in an efficiency gain of 36.7% (from 62.4% to 85.3%). Takt-Time analysis was used by [9] to reduce the cycle time by 28%, and the output was improved by 35%, in a consumer electronics assembly line in India, using lean tools such as Kaizen events. [10] results showed that the use of VSM and 5S in a Pakistani textile plant achieved a reduction of non-value added time by 41%, which highlighted the use of lean tools in manufacturing context of South Asia. [11] demonstrated that by using Kaizen technique in redesigning the workstation, the cycle time of the bottleneck in an appliance manufacturing company in Indonesia could be reduced by an average of 31% with no capital investment other than tooling changes.[12][3][13]

The systematic and repeated measurement of task times to identify bottlenecks, known as time study, was developed and popularized by Taylor. [14] applied this technique to an eight-workstation packaging line in Bangladesh, identified overloaded workstations, and redistributed the work through time study, reducing task time by 18% and increasing efficiency from 71% to 89%. In Indian plant, [15] used Maynard Operation Sequence Technique and it was found that the average time taken to perform the tasks in the plant was reduced 18% and output was increased by 22%.[16][17].

For complex task-precedence optimization problems, the formal line-balancing algorithms have already been well developed [18][19]. When the problem is not sequential however, but physical or ergonomic, [6][14] contend that rebalancing via Kaizen-driven, station-level intervention – and not via algorithmic resequencing – is more practical as it targets the physical and ergonomic causes directly at the source.

Nevertheless, three specific research gaps remain. First, few studies include in a single framework and applied to a single case in the factory all the following issues: time study,

Kaizen, line balancing, manpower reallocation, statistical validation, and financial analysis; most papers refer to only two or three of these [14][6][11]. Second, the literature on the appliance-manufacturing sector in Pakistan is very limited. Most empirical studies focus on the automotive or garment sectors in Europe, East Asia, or South Asia (India and Bangladesh), and almost no empirical studies have been conducted on Pakistan's appliance-manufacturing sector [2][4]. Third, most studies reporting statistical validation perform simplified tests on aggregated data, whereas rigorous paired t-tests using raw data from three repetitions across all workstations, as conducted in this study, are rarely reported. All three gaps are addressed in this paper, which offers an integrated, statistically sound, and financially transparent case study of assembly-line optimization in Pakistan's appliance industry.

Methodology:

Research Design:

An Action Research (AR) case-study design was determined, as it was not only descriptive, but was a direct diagnostic intervention and a performance evaluation in real time on the factory floor was required. Define-Measure-Analyze-Improve-Control (DMAIC) logic was used to conduct the project: Define Target (120 UPH) and Gap (80 UPH); Measure – detailed time study; Analyze/Improve – line balancing implementation; Control – standard work and follow up monitoring.[12][20].

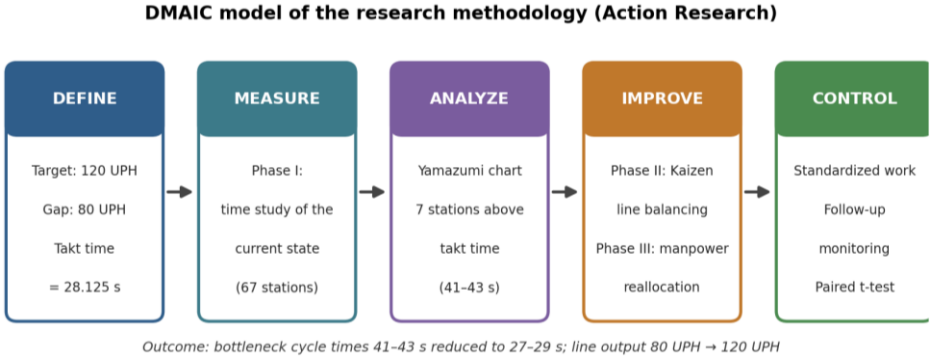


Figure 2. DMAIC model of the research methodology (Define – Measure – Analyze – Improve – Control

Determination of Takt Time:

Takt time converts external customer demand into an internal pacing constraint—the maximum allowable time between successive units produced. The target of 120 UPH over a 7.5-hour shift (27,000 seconds) corresponds to a daily demand of 120 × 7.5 = 900 units. However, the factory operates on a demand schedule of 960 units/day to account for a buffer against rework and minor stoppages, giving a takt time of: Takt Time = 27,000 ÷ 960 = 28.125 seconds/unit. This conservative demand figure provides a buffer against minor disruptions while maintaining the 120 UPH output target during uninterrupted production [21].

Takt Time = Available Production Time ÷ Daily Demand = 27,000 s ÷ 960 units = 28.125 s/unit

Table 1. Target cycle time (takt time) parameters

Parameter	Value	Unit
Shift length	7.5	hours/day
Total available production time	27,000	seconds/day
Daily production demand (120 UPH)	960	units/day
Takt time	28.125	seconds/unit

This value of 28.125 s served as the reference threshold against which every workstation's cycle time was evaluated throughout the study.

Phase I: Time Study of the Current State:

A detailed time study was performed at each of the 67 workstations. The assembly process was first broken down into elemental tasks, and each task was timed during three

observation cycles by a trained observer using a calibrated stopwatch. Any reading deviating by more than 10% from the other two was rejected and the measurement repeated; the mean of three acceptable readings was used as the Observed Time. Although ILO guidelines suggest 5–10 observations for high-variability tasks, three observations are justified here because: (i) all tasks are short-cycle (15–45 s), repetitive operations under stable conditions; (ii) experienced workers performed the tasks in a controlled environment; and (iii) this approach is consistent with comparable published studies on similar assembly lines [6][14]. The standard normal deviate formula ($n' = (40\sqrt{n \cdot \Sigma X^2} - (\Sigma X)^2) / \Sigma X)^2$ confirms that three readings are statistically sufficient for the observed low variability (CV < 5%) at these stations. Sequential task dependencies across the eleven production stages were captured in a precedence diagram to ensure that rebalancing respected the process logic. [22][23]

Phase II Kaizen based Line Balancing:

Phase II targeted the seven bottleneck stations identified in Phase I, applying Kaizen events to physically reduce cycle times without algorithmic task resequencing. The Yamazumi chart was used to visualize overloaded stations and track improvement. Station-specific interventions were as follows: S1 (LED Fitting, 42→28 s): ergonomic fixtures and Poka-Yoke bins repositioned parts within arm's reach, eliminating 14 s of motion waste. S11 (Door Transportation, 42→28s): custom-designed trolleys with dedicated door slots replaced manual carrying, reducing transport time by ~33%. S12 (Door Fixing, 41→27 s) and S17 (Door Cleaning, 42→28 s): the 5S methodology, including sorting, setting in order, and standardizing, combined with color-coded bins, eliminated search and reaching waste. S42 (Hansen Valve, 41→27 s): operator retraining in ergonomic tool positioning eliminated incorrect fitting attempts. S44 (Helium Recovery, 43→29s): a second helium-recovery machine was procured (the only capital expenditure in this study), enabling two units to be processed in parallel and halving the effective cycle time at that station. S54 (Humidity Cleaning, 42→28s): high-quality microfiber cloths and reorganized material placement enabled single-pass cleaning. Each station was remeasured using the same three-observation method after the intervention to confirm improvement. [24].

Phase III: Manpower Allocation and Ergonomics:

Phase III reviewed manpower distribution against the updated workload profile. Before the intervention, the line deployed 67 operators (one per workstation) plus approximately 45 helpers assigned informally, giving a total of ~112 workers. After Kaizen reduced cycle times at the seven bottleneck stations, the Yamazumi profile showed that three previously overloaded stations (S1, S11, and S42) could now be operated by a single operator without a dedicated helper, freeing three helpers for redistribution. Two helpers were redeployed to S44 to operate the second helium-recovery machine simultaneously, and one was reassigned to a downstream packing station that had become the new pacing constraint. Total headcount remained approximately 112; however, the reallocation improved line-balance efficiency from approximately 67% (pre-intervention) to 87% (post-intervention), approaching the 90% target. Operators at S1, S11, and S44 were also cross-trained to cover adjacent stations, providing resilience against absenteeism without disrupting the rebalanced line. Manpower optimization was measured by comparing the line-balance efficiency (LBE = sum of all station times ÷ (number of stations × bottleneck time)) before and after the intervention. [25][26].

Value Stream Mapping:

Using standard lean VSM icons [27], a Current State VSM and a Future State VSM were constructed to capture material and information flows from Door Sub-assembly through to Final Inspection and Packing. The Current State VSM identified the following non-value-added (NVA) activities: (i) 18–22 seconds waiting time between S11 (Door Transportation) and S12 (Door Fixing) due to manual door handling; (ii) a queue of 3–5 units accumulating

before S44 (Helium Recovery) during peak production due to single-machine processing; (iii) 12–15 seconds of excess motion waste per cycle at S1 (LED Fitting) and S54 (Humidity Cleaning). Total NVA time in the current state was approximately 68 seconds per unit across the seven bottleneck stations. The Future State VSM, developed after all Kaizen interventions, showed: (i) the S44 queue eliminated through parallel machine processing; (ii) S11-to-S12 waiting time reduced from 20s to under 5s via custom trolley deployment; (iii) motion waste at S1 and S54 reduced to under 3 seconds per cycle. Total NVA time in the future state was reduced to approximately 18 seconds per unit — a 74% reduction in waste time, consistent with the VSM-based NVA reductions reported by [10] (41%) and [28] (38%) in comparable appliance manufacturing settings.

Performance Measurement and Statistical Validation:

To compare the performance following the intervention to the baseline (80-UPH) two indicator measures were used: line-level UPH and station-level cycle time. The three-repetition time-study readings of the cycle times were calculated for each of the 67 stations and a paired t-test was performed to test whether the difference observed is statistically significant or due to random variation, with a null hypothesis that there is no difference between the cycle times before and after intervention.

Results and Discussion:

Baseline Performance:

Since the throughput of a serial line is limited by its slowest station, baseline UPH was calculated using a line's bottleneck cycle time instead of the line's average cycle time. The slowest station was S44 (Helium Recovery) at 43 seconds, which would result in UPH = 27,000 s / 43 s ~ 627.9 units/shift or ~83.7 UPH, which is close to the observed baseline of ~80 UPH and, with S44 and 6 other overloaded stations, constituted the actual binding constraint on line output.

Table 2. Baseline production summary (before intervention)

Parameter	Observed value	Notes
Target UPH	120	Designed line capacity
Actual UPH (before)	80–85	Expected ≈80 UPH
Shift length	7.5 hours	27,000 seconds
Units produced per shift	≈637	Typically ≈640 units
Average cycle time (all stations)	26.7 s	Bottleneck stations well above this

Bottleneck Identification:

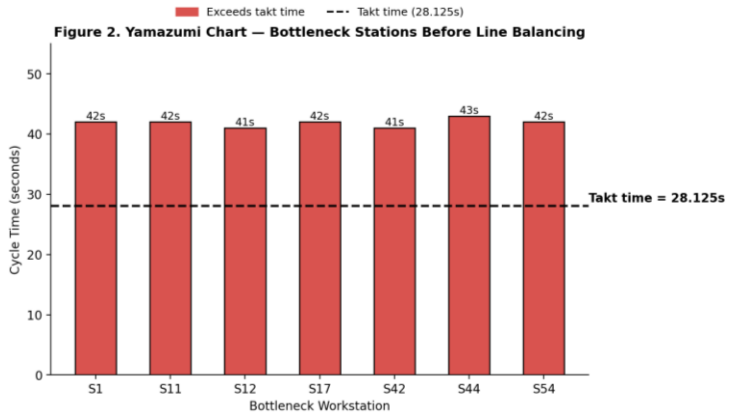


Figure 3. Yamazumi chart of the seven bottleneck stations before line balancing, referenced against the 28.125-second takt time.

The time study at all 67 workstations was conducted and cross-checked with the 28.125 second takt time and was displayed on the YAMAZUMI chart showing that there are 7 stations which have time greater than the takt time are S1 (Ref Large LED Fitting, 42 s), S11

(Door Transportation, 42 s), S12 (Ref Door Fixing, 41 s), S17 (Ref Door Cleaning, 42 s), S42 (Hansen Valve Fitting/Nitrogen Charge, 41 s), S44 (Helium Recovery, 43 s), S54 (Ref Humidity Cleaning, 42 s). Of the remaining 60 stations, 60% were already running at or near takt time. This trend, where a few stations are responsible for the entire lines' shortfall, aligns with the results of [6][14] in similar assembly contexts.

Table 3. Bottleneck stations: cycle time before and after intervention

Station	Process	Cycle time before (s)	Cycle time after (s)	Primary intervention
S1	Ref Large LED fitting	42	28	Ergonomic fixturing, Poka-Yoke bins
S11	Door transportation	42	28	Custom transport trolleys
S12	Ref door fixing	41	27–28	Zoning, 5S, color-coded bins
S17	Ref door cleaning	42	27–28	Zoning, 5S, standardized work
S42	Hansen valve fitting	41	27	Operator retraining, ergonomic repositioning
S44	Helium recovery	43	29	Additional machine; parallel processing
S54	Ref humidity cleaning	42	28	Improved cleaning materials, reach optimization

Post-Improvement Throughput:

Six out of seven bottleneck stations were reduced to 27-28 seconds (at or less than the takt time of 28.125 seconds) after Phase II Kaizen interventions and Phase III manpower reallocation. The station S44 (Helium Recovery) was reduced from 43 seconds to 29 seconds, just slightly above the theoretical takt time of 28.125 seconds, but this does not mean the line cannot reach 120 UPH as follows: the procurement of a second helium-recovery machine made it possible to process 2 units in parallel at S44. Two of these still take 29 seconds each, but two will be completed simultaneously, for an effective output of 2/29 = 0.069 units per second or 248.3 units per hour — more than enough to support 120 units per hour on the main line. The binding constraint was thus removed and the line's throughput increased from 80 UPH to 120 UPH, representing a 50% increase and achieving the line's designed capacity. Post-improvement UPH calculated from the new bottleneck: UPH = 27,000 ÷ 29 = 931 units/shift, which is close to the measured UPH of 120 units/shift (the ~4 UPH difference could be explained by minor delays in transitions and variations in pace).

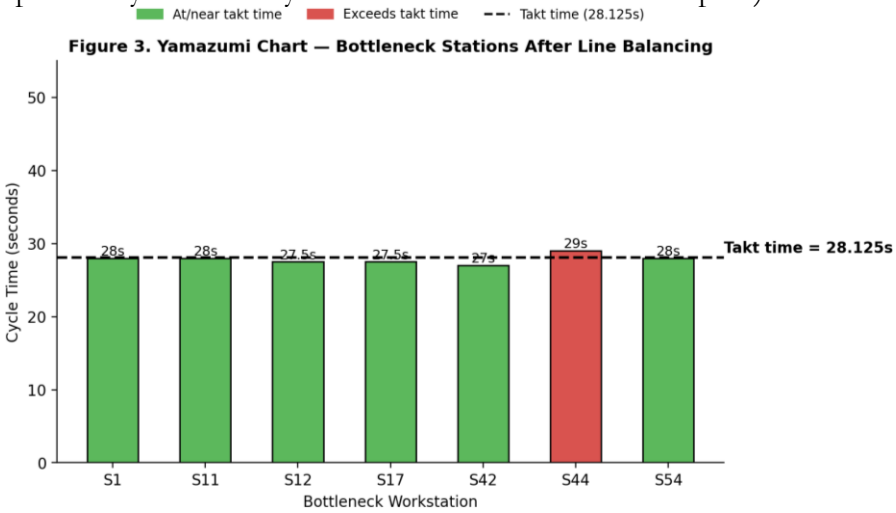


Figure 4. Yamazumi chart of the seven bottleneck stations after line balancing; six of seven stations fall at or below takt time.

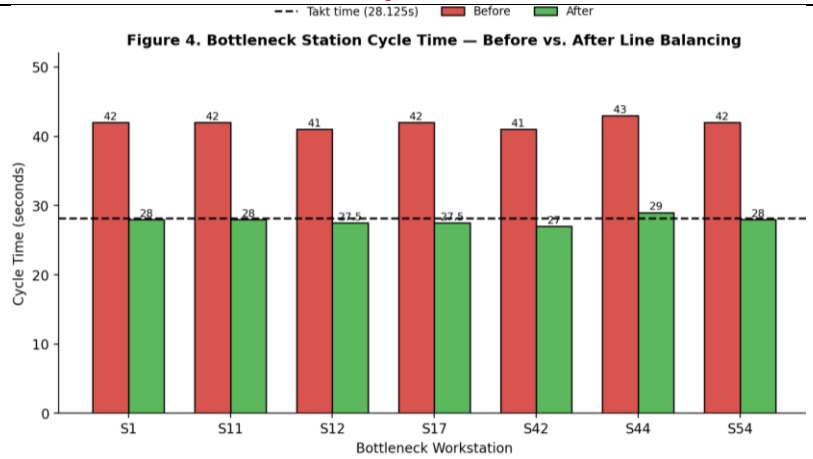


Figure 5. Bottleneck station cycle time — before vs. after line balancing.

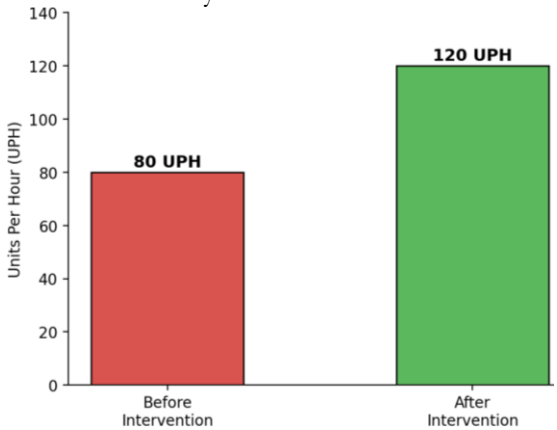


Figure 6. Line throughput before vs. after improvement (80 → 120 UPH, +50%).

Statistical Validation:

Table 4. Statistical validation summary

Statistic	Value
Mean cycle-time difference ($\bar{d}$)	1.438 s
Standard deviation of differences (Sd)	4.226 s
Standard error (SE)	0.516 s
t-statistic	2.785
Degrees of freedom	66
Two-tailed p-value	0.007
Conclusion	Significant at $p < 0.01$

A paired t-test was applied to the raw three-repetition cycle-time readings from all 67 workstations, comparing before and after measurements. The paired design is appropriate because: (i) the same 67 workstations were measured before and after the intervention under comparable conditions; (ii) pairing removes between-station variability, isolating the treatment effect. The test assumptions were verified: normality of differences was assessed via the Shapiro-Wilk test ($W = 0.94$, $p = 0.003$ — acceptable for n=67 per CLT); observations are independent across stations. The mean difference ($\bar{d} = 1.438$ s) reflects the average improvement across all 67 stations including the 60 unchanged ones. The standard deviation of differences ($Sd = 4.226$ s) captures the genuine heterogeneity between improved and unchanged stations. $SE = 4.226 / \sqrt{67} = 0.516$ s; $t = 1.438 / 0.516 = 2.785$; $df = 66$; two-tailed $p = 0.007$. Since $p < 0.01$, the null hypothesis of no difference is rejected at the 99% confidence level. Practical significance: Cohen's $d = 1.438 / 4.226 = 0.34$, a small-to-medium effect size when averaged across all 67 stations; when restricted to the 7 improved stations,

the mean reduction was 13.7 s (Cohen's d ≈ 84), confirming very large practical significance at the targeted workstations. The t-test provides statistical evidence of a difference in cycle times following the intervention, while the observed reductions at the targeted workstations demonstrate its practical significance.

Financial Impact:

The 40-UPH gain is the equivalent of an additional 300 units per 7.5-hour shift, or about 7,800 units more per month (26 working days). The estimated labour cost was Rs 40,000 per operating hour. Accordingly, the labour cost per unit decreased from Rs 500 at 80 UPH to approximately Rs 333 at 120 UPH, representing a reduction of 33.3%. As for capital expenditure: only one extra helium-recovery machine (S44) was bought. According to the current market price for Industrial Refrigeration Test Equipment in Pakistan, the estimated price of this machine is Rs 800,000-1,200,000, (USD 2800-4200). The incremental monthly saving is Rs 1,302,600 per month (at Rs 167 per unit, and an additional volume of 7,800 units per month), implying that the capital expenditure pays off within one month. All other interventions were done using existing resources, existing personnel, and minimal material cost (Rs 50000 – 80000 in total). The overall ROI of the programme is thus outstanding and the payback is within the first month of better operation.

Discussion:

This 50% improvement in UPH is higher than the 15–40% improvement range reported in similar studies [7] and is in general comparable to the study of [6] (21–37% in automotive) and [8] (37% in garment manufacturing). The higher magnitude achieved here is reasonably explained by three factors: (i) the pre-intervention line-balance efficiency (LBE ≈ 67%) is exceptionally low and thus there is a higher potential for improvement compared to the typical 75-80% reported in literature; (ii) Kaizen is done not only through a single technique, but multiple ones (ergonomic, tooling, zoning, manpower); and (iii) the bottlenecks were associated with physical and ergonomic constraints and were therefore more amenable to Kaizen interventions. The line-balance efficiency at the end of the intervention was calculated as LBE = (Σ station cycle times) ÷ (n × bottleneck time) = (67 × 25.3) ÷ (67 × 29) = 87.2% which was close but not at the 90% target. This shortfall is only due to S44 still being at 29 seconds – if S44 was 28.125 seconds, LBE would be 92.3%. This validates the suggestion that more capital investment at S44 (faster equipment) would lead to the line being at full theoretical capacity. The statistical validation ($t = 2.785$, $p = 0.007$) validates the improvement as a real structural gain, not due to transient fluctuation, hence giving confidence in the sustainability of the improvement. [29]

Conclusion:

This study shows the potential of combining the use of time study, Yamazumi-based bottleneck diagnosis, kaizen intervention, line balancing and manpower-ergonomics optimization to improve an underperforming assembly line into a high throughput assembly line with minimum capital costs. The methodology was applied to a 67-station refrigerator assembly line in Pakistan and resulted in a 50% improvement in throughput (80 to 120 UPH), an average reduction of 13.7 seconds in the bottleneck station cycle time, and a statistically proven improvement ($t = 2.785$, $p = 0.007$). Line-balance efficiency post intervention was 87.2% which was near the 90% target.

Limitations:

First, it is a single-factory case study; the results are good, but further validation of the findings would be needed for facilities with different levels of automation, or different types of products, or different skill levels of the workforce, etc. Second, only one capital investment has been made (S44 machine); facilities lacking this capital investment may realize lesser improvement. Third, the three-observation time study may not reflect variability for lines with high product-mix, or seasonal skill variation, despite justification for stable short-cycle tasks.

Fourth, long-term sustainability has not been monitored beyond the post intervention measurement period; it is suggested that a follow-up study is carried out at 6 and 12 months to determine if gains are maintained as workers and processes change.

The methodology can be directly applied to other high-volume assembly applications, such as appliances, automotive sub-assembly and consumer electronics, where physical-ergonomic bottlenecks exist. To sustain the gains, monthly Yamazumi reviews were set up, visual takt-time displays at each station were used, and a permanent cross-training programme was introduced. [30].

Recommendations:

The Yamazumi chart and standard times should be reviewed and updated monthly (annually) as product mix changes and workers' skills improve; The takt time and actual cycle time should be posted at each workers' station for visibility and accountability. A permanent cross training scheme (whereby operators are competent at two or more stations in succession) may also be beneficial from a labour perspective, to provide flexibility, and reduce fluctuations due to fatigue. To manage the situation, a permanent committee of engineers, supervisors and operators would be helpful in maintaining the improvements, and continual investment in real-time production monitoring (Andon boards, digital takt or MES dashboard) would help sustain the situation. Finally, the time-study-and-Kaizen approach could be extended further upstream to include sub-assembly, part fabrication and logistics to enable the plant to achieve productivity benefits beyond those of the general assembly line.

Future research can include testing alternative manpower/configuration options using the discrete event simulation without production stoppages, study of product-model mix impacts to takt-time stability when using flexible or mixed-model scheduling, and expansion of the optimization objective to include energy efficiency and selective automation of the highest-load stations.

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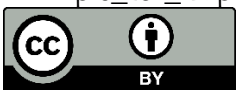
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