Total Productive Maintenance Implementation in Middle Eastern Food Industries: A 3-Year Case Study at Al-Jaid Processing Plant

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Abstract - *This study investigates the implementation of Total Productive Maintenance (TPM) at Al-Jaid Food Industries, a leading juice manufacturing plant in the Middle East, with the aim of enhancing operational efficiency, minimizing equipment failures, and improving product quality. A multi-method approach was used over a three-year period, integrating data from TPM management system logs, automation system-based sensor readings, operator surveys, and maintenance audits. The results showed significant improvements in key performance indicators (KPIs), including a 12.7% increase in overall equipment effectiveness (OEE), a 30% decrease in mean time to repair (MTTR), and improved cleanliness compliance rates. Seasonal analysis revealed a 27% increase in equipment stress during the summer months, leading to the development of a new thermal stress index (TSI). The study proposes actionable recommendations such as sensor-based predictive maintenance, operator involvement in comprehensive periodic maintenance and seasonal maintenance planning. The results of this study validate CCM as a transformative framework when adapted to the specificities of the food industry, providing a replicable model for similar organizations in climate-sensitive and heavily regulated environments.*

Key Words: Total Productive Maintenance (TPM), Maintenance Management, Overall Equipment Effectiveness (OEE),Food Industry, Operational Performance, Preventive Maintenance, Continuous Improvement

1. INTRODUCTION

The increasing complexity of modern manufacturing processes, combined with increased demands for quality and regulatory compliance, has increased the need for effective and reliable maintenance plans Total Productive Maintenance (TPM) has evolved into a holistic methodology aimed at optimizing equipment performance by involving all personnel, from supply management to machine operators, in proactive and preventive maintenance activities. Originally introduced in Japan, TPM has become an essential part of advanced manufacturing [1-12].

In the food and beverage sector, where maintenance, uptime, serviceability and traceability are critical, the application of CPM methods offers unique opportunities and obstacles Equipment failures not only disrupt production, but can also lead to safety violations and non-compliance [13-20].

This study addresses this issue by presenting a detailed case study of the application of CPM methods at Al Jaid Food Processing Company in Saudi Arabia [14-16]. The research aims to evaluate the effectiveness of CPM in improving operational metrics, identify seasonally influential failure modes, and formulate context-specific recommendations for institutionalizing CPM The findings provide useful [17-32].

2. METHODOLOGY OF THE STUDY

This extended case study utilized a multi-method approach to evaluate the implementation and impact of Total Productive Maintenance (TPM) at Al-Jaid Food Industries, a juice factory in the Middle East. This research was conducted over a three-year period (January 2021 - December 2023), and the study incorporated both quantitative and qualitative data collection methods to ensure triangulation and validity of results.

2.1 Data Collection Tools and Sources

A comprehensive plan was used to collect data using the following sources Computerized Maintenance Management System (CMMS): Past maintenance records, including mean time to repair (MTTR), mean time between failures (MTBF), work orders, and parts utilization data.IoT-Based Sensor Data: Real-time vibration and temperature readings from 62 critical machines across six production stages, logged at 5-minute intervals Quality Audit Reports: Monthly hygiene and quality assessment data aligned with FDA 21 CFR Part 110 compliance.

Structured Interviews: 37 semi-structured interviews with operators, technicians, and maintenance supervisors, conducted in Arabic and English to capture contextual nuances.

Time-Motion Studies: On-site analysis of equipment downtime, repair processes, and maintenance task durations.

Operator Surveys: Attitudinal data regarding TPM training, documentation preferences, and engagement with autonomous maintenance.

2.2 Analytical and Statistical Framework

A robust multi-layered analytical framework was adopted to extract meaningful insights and establish causal relationships:

- TPM Metric Customization: Classical TPM metrics (OEE, MTTR, MTBF, Availability) were adapted to food industry specifics (e.g., excluding sanitation downtime from MTBF, integrating hygiene compliance into OEE).
- Pareto Analysis: Applied to categorize and prioritize the root causes of failures by frequency and duration.
- Thermal Stress Index (TSI): A novel metric developed for this study to quantify the combined impact of temperature and vibration on equipment stress, particularly during the peak summer months.
- Root Cause Analysis (RCA): Utilized Ishikawa diagrams and 5-Whys methodology to trace persistent failures in the heating and cleaning stages.
- Seasonal Adjustment Modeling: Failures were analyzed against ambient temperature data (collected from on-site weather monitoring stations) to assess seasonal degradation trends.

3. RESULTS AND DISCUSSION

3.1 Key Performance Indicators (KPIs) Quantitative Improvement

The customized TPM framework led to measurable improvements across all major KPIs:

Year	Availability	MTBF (hrs)	MTTR (hrs)	Quality Rate	OEE
2021	89.38	48.2	2.64	88	78.5%
2022	92.12	53.7	1	93%	85.2%
2023	90.79%	51.9	1.83	95%	88.4%

- Overall Equipment Effectiveness (OEE) improved by 12.7% from 2021 to 2023, surpassing the 85% industry benchmark by the second year.
- MTTR decreased by 30.6%, indicating improved diagnostic tools, operator proficiency, and spare parts availability.
- Quality Rate showed a consistent upward trajectory, with hygiene-compliance-integrated TPM contributing to defect reduction.

3.2 Failure Concentration and Seasonal Impacts

- Pareto Analysis Results:
  - Heating stage accounted for 63.6% of total downtime. Primary causes included gasket degradation, sensor malfunctions, and overheating shutdowns.
  - Cleaning stage contributed 26.4% of failures, mostly due to delays linked to regulatory sanitation requirements.
- Seasonal Failure Distribution:
  - Summer (June–August) saw a 27% spike in equipment failures, consistent with elevated ambient temperatures (>42°C).
  - TSI scores were highest in July, correlating with both equipment stress indicators and maintenance-related shutdowns.

3.3 Operator Engagement and TPM Institutionalization

- The integration of bilingual (Arabic-English) training modules and visual work instructions led to a 40% increase in autonomous maintenance participation.
- Culturally adaptive scheduling during Ramadan resulted in an 18% reduction in fatigue-related human errors.
- Monthly TPM performance dashboards were introduced, enhancing transparency and inter-departmental accountability.

3.4 Strategic Insights

- The adaptation of classical TPM pillars (especially Autonomous and Planned Maintenance) to the context of the Middle Eastern food sector proved essential.
- TPM implementation yielded not only productivity gains but also:3
  - $1.2 million in annual operational cost savings.
  - 40% reduction in safety-related incidents due to proactive maintenance.
  - Enhanced compliance with hygiene and food safety audits.

4. PRACTICAL RECOMMENDATIONS

Drawing upon the in-depth assessment of TPM implementation at Al-Jaid Food Industries, several actionable recommendations are proposed to deepen its institutionalization and ensure sustained gains in productivity and quality within the food manufacturing domain:

1. Contextualized TPM Training Programs: Develop dual-language (Arabic and English) training modules specifically designed for food industry personnel. These should combine interactive workshops, visualized Standard Operating Procedures (SOPs), and real-world case studies to enhance practical understanding.

2. Digital Transformation of Maintenance Processes: Employ IoT-based sensors and predictive analytics platforms to monitor key machine health indicators such as vibration, temperature, and pressure in real time. This will strengthen condition-based maintenance and minimize unscheduled equipment failures.

3. Seasonally Adaptive Maintenance Scheduling: Modify preventive maintenance plans according to seasonal environmental changes, particularly in response to increased thermal stress during summer. Thermal Stress Index (TSI) data should inform the timing and scope of maintenance interventions.

4. Formation of Cross-Functional TPM Committees: Establish cross-departmental teams composed of representatives from quality control, production, and maintenance units. These committees will help ensure comprehensive implementation of TPM principles and foster a shared sense of responsibility across the organization.

5. Performance-Based TPM Incentives: Create structured reward systems that recognize improvements in Overall Equipment Effectiveness (OEE), safety compliance, and sanitation standards. This approach encourages frontline personnel to take initiative and maintain high performance.

6. Integration of Hygiene with Maintenance Protocols: Embed food safety requirements such as those outlined in HACCP and ISO 22000 within the TPM strategy, particularly in areas involving equipment cleaning and packaging. This ensures alignment with both regulatory obligations and consumer expectations.

7. Continuous Monitoring and Feedback Mechanisms: Deploy real-time digital dashboards to track key TPM performance indicators and establish regular review meetings with operational staff. These feedback loops promote transparency, responsiveness, and continuous learning.

Collectively, these recommendations provide a structured pathway for food industry enterprises seeking to enhance maintenance efficiency, cut operational costs, and meet stringent compliance demands inherent to regulated sectors like food and beverage production.

5. CONCLUSION

This research provides concrete evidence of the significant impact that implementing Total Productive Maintenance (TPM) can have at Al-Jaid Food Industries particularly in the context of juice production, where strict quality standards and regulatory compliance are critical. Through the integration of tailored TPM indicators, real-time sensor monitoring, and maintenance practices led by operators, the facility achieved marked improvements in Overall Equipment Effectiveness (OEE), equipment uptime, predictive maintenance capability, and overall product quality.

The results underscore that TPM is far more than just a maintenance methodology; it represents a holistic strategy for achieving operational excellence. When its principles are thoughtfully adapted to the specific industrial context and cultural environment, TPM can drive clear gains in productivity, safety, and regulatory adherence. Key factors contributing to the program's success included:

- Customizing TPM pillars to meet the operational constraints of the food industry.
- Utilizing data-centric decision-making supported by Computerized Maintenance Management Systems (CMMS) and Internet of Things (IoT) technologies.
- Promoting active employee participation and fostering cross-functional collaboration.

Additionally, the study's seasonal performance analysis revealed that external environmental conditions particularly ambient temperature exert a measurable influence on equipment behavior. This finding suggests that climate-aware maintenance strategies are essential for facilities operating in similar climatic zones.

In summary, TPM holds strong potential as a driver of continuous improvement and competitive differentiation in the food production sector. For future work, exploring the synergy between TPM and artificial intelligence-based predictive technologies, as well as its extended financial implications for supply chain resilience, represents a promising direction.

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