Operational improvement of the technological process in instant noodle production

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Abstract

Introduction. The aim of the study is to improve the technological process of instant noodle production, ensuring stable and uninterrupted operation in the absence of electricity supply.

Materials and methods. To assess the effectiveness of the proposed backup power solutions, the Lean thinking methodology was applied. The analysis was based on overall equipment effectiveness (OEE), downtime duration, and seasonal blackout frequency. Modeling was performed using mathematical matrices, histograms, box plots, and combined graphs with dual Y-axes.

Results and discussion. It was found that power outages cause significant disruptions to the continuity of the instant noodle production process. Calculations showed that the recovery time after a power outage exceeds the working cycle by a factor of 2.3: 2100 > 937 seconds. This, in turn, leads to reduced production line performance and increased risk of defects. By modeling several blackout scenarios (short-term, medium-duration, and long-term), the seasonal dynamics of outages over a 12-month period were analyzed. It was revealed that the highest number of outages occurred in June-July, while the longest outages were observed in November-December.

Analysis of the results and validation of the effectiveness of the proposed solutions to ensure uninterrupted operation of the instant noodle production line indicate that the choice of backup power type should be based on the intensity and nature of power outages. In the case of short and infrequent outages (100-25 hours / year), the implementation of a manually started generator is sufficient, significantly improving the situation: the production cycle is reduced to 0.287 seconds, and overall equipment effectiveness (OEE) increases to 76.36 %.

In contrast, under medium-duration outages (350-380 hours / year), the implementation of a comprehensive solution proves most effective, achieving an overall OEE of 78.96 % and minimizing deviations from the nominal cycle (0.288 seconds), which significantly shortens the production cycle duration, minimizes productivity losses, and maintains process stability. During prolonged outages (over 600 hours / year), the highest performance indicators are also achieved with the comprehensive approach, ensuring stable equipment operation at an OEE level of 78.96 % and restoring the nominal cycle time to 0.288 seconds, which is equivalent to uninterrupted power supply conditions.

Conclusions. The research has shown that the rationality of choosing a technical solution is determined by the frequency, duration, and nature of power outages. If the intensity of external power outages increases, a solution consisting of a generator + ATS + UPS is needed to maintain process stability and minimize losses.

Introduction

The efficiency of the food industry is recognized as one of the key components of food security for the population in any country (Mbow et al., 2019). This issue becomes particularly critical under martial law conditions, where ensuring access to food in crisis situations – such as resource supply disruptions, power outages, and security threats – is essential. Therefore, addressing the challenges faced by food industry operators and developing solutions to overcome or mitigate them is a crucial task. It has been identified that production-related costs account for a significant share of the total expenditures in the food industry (Womack et al., 2018). Reducing these costs through operational improvements has a direct impact on the ability to sustain production activities (Anderson et al., 2020).

One of the most effective tools to achieve this goal is the application of Lean-Thinking – a comprehensive management and improvement concept aimed at eliminating waste and optimizing all stages of production processes: from technological operations to interactions with suppliers and consumers (Womack et al., 2018). Research in this field is focused on maximizing process value for the consumer while minimizing the manufacturer's resource expenditure, including human effort, equipment usage, and especially downtime (Eskandari, Hamid, Masoudian, Rabbani, 2022).

While it is impossible to completely eliminate losses in the production process, ensuring its stable and uninterrupted operation under any conditions is essential (Pereira et al., 2022). A literature review revealed a lack of research specifically addressing the issue of uninterrupted production line operation during power outages at the global level, making direct comparisons of research outcomes currently unavailable. This is primarily due to the previously low relevance of such studies in countries with stable security and economic environments. However, with the rapid growth of global threats in recent years, this issue is gaining increasing importance, particularly in EU countries (Pereira et al., 2022).

It is also worth noting that under conditions of stable power supply, the control of technological parameters is carried out continuously – both manually and automatically. However, power outages directly affect all critical points in production (Haes Alhelou et al., 2019), as they disrupt temperature conditions during various process stages; halt production lines when the product is in critical zones (thermal treatment, cooling, forming); and create situations where parameter control becomes either impossible or irrelevant, since even short power interruptions require complete system reinitialization and repeated control procedures (Salman et al., 2023).

The scientific value lies in developing an effective theoretical tool based on mathematical and digital methods that can solve practical problems related to the stable functioning of technological processes and reduce production costs for food industry operators.

Based on the above, the object of this research is the technological process of instant noodle production, chosen due to the sufficient number of operations and process parameters that allow for more accurate and relevant results under power outage conditions. It is important to note that the results of operational improvements obtained in this research can be scaled to other sectors of the food industry, as one of the key advantages of Lean-Thinking is the universality of its tools, which can be applied to any production or process (Bittencourt et al., 2021).

The aim of the research is to justify operational improvement measures for food production processes in order to ensure stable and uninterrupted operation in the face of external disturbances – specifically, power supply disruptions.

Materials and methods

Materials

The research focused on the technological process of producing instant noodles – a pre-cooked and dried product typically sold in brick form with seasoning sachets. The production process consists of the following main operations: sifting and weighing flour and other ingredients, dough mixing, resting, rolling, cutting, steaming, separation, frying, cooling, packaging, rejection of defective products, manual packaging, palletizing, transportation to the warehouse, and storage.

The research was conducted at the facilities of a food market operator located in the Kyiv region. The operating time was based on the durations of production stages as defined in the technological guidelines under a three-shift schedule, 24 hours a day, 360 days a year. The total production period duration was 8.760 hours, of which 8.640 hours were allocated to operational cycles, and 120 hours were reserved for planned downtime not related to technical needs (e.g., holidays).

Given the stated production duration, the planned output was 125 million units. However, the actual output reached 107 million units, of which 104 million met quality standards.

Methods

Duration of technological stages in instant noodle production

The duration of each production operation (carried out according to technological instructions for the specific product) was measured manually using an electronic chronograph. The total production time for instant noodles was calculated using formula 1: (Varsha et al., 2025):

$$\sum_{n=1}^{1} TO \quad (1)$$

where n – number of technological operations;

TO – duration of a technological operation, s.

Production takt time and production cycle time

The production takt time and the production cycle time were calculated using formulas 2 and 3 (Taifa et al., 2019):

$$T_{takt} = \frac{T_p}{N} \quad (2)$$

$$T_{cycle} = \frac{T_{a.p.}}{N_{n.d.p.}} \quad (3)$$

where T_p is planned production time, s;

N is ordered product batch, units;

$T_{a.p.}$ is actual production time, s;

$N_{n.d.p.}$ is ordered batch of non-defective products, units.

Calculation of overall equipment effectiveness

The concept of Overall Equipment Effectiveness (OEE) was proposed by Japanese engineer Seiichi Nakajima (Corrales et al., 2020). OEE provides a systematic way to evaluate losses related to downtime, speed reduction, and defects, based on three components: availability, performance, and quality (Biswas, 2024).

OEE is calculated as the product of these three components using formula 4:

$$\text{OEE} = Av \cdot Pr \cdot Ql \quad (4)$$

Availability Av (represents losses due to downtime, %), line Performance Pr (expressed as % %), Quality Ql (share of good-quality products without defects, %) are calculated using formulas 5–7, respectively:

$$Av = \frac{T_{a.p.}}{T_{p.}} \cdot 100\% \quad (5)$$

$$Pr = \frac{N_a}{N_{t.p.}} \cdot 100\% \quad (6)$$

$$Ql = \frac{N_{f.w.d.}}{N_{a.d.p.}} \cdot 100\%, \quad (7)$$

where N_a is actual product output, units;

$N_{t.p.}$ is theoretical production output, units;

$N_{a.d.p.}$ is actual output of non-defective products, units.

Power supply modeling

Three power outage duration scenarios were selected for modeling, based on the average annual duration of electricity supply interruptions. Subsequently, their impact on production process losses and equipment efficiency of the production line was evaluated.

Each scenario was assigned a corresponding designation: short-term outages (approximately 100–125 hours per year) – Scenario 1; medium-duration outages (approximately 350–380 hours per year) – Scenario 2; long-term outages (over 600 hours per year) – Scenario 3 (Table 1). These values were obtained through monitoring, recording, and summing the durations of outages throughout the calendar working year (Pereira et al., 2022).

Table 1

Modeling scenarios of downtime duration for the instant noodle production line during the calendar working year

Scenario Name	Type of Outage	Outage Duration, hours / year
Scenario 1	Short-term	100-125
Scenario 2	Medium-term	350-380
Scenario 3	Long-term	≤ 600

Backup power supply solutions

Two possible backup power solutions were identified for assessing response effectiveness during outages:

Simple solution – "Generator (manual start)": purchasing and installing a diesel generator with appropriate power capacity. The downside of this option is the need for manual startup (time loss due to extra actions) and generator startup time (7–15+ minutes on average for a 10 kW model (Salman et al., 2023)), along with the risk of failure to start in advance.

Comprehensive solution – "Generator + ATS + UPS (instant switchover)": a long-term, efficient solution combining a generator, automatic transfer switch (ATS), and uninterruptible power supply (UPS with a battery set). This combination provides an immediate switchover without voltage drop or equipment damage, minimizing time loss, increasing quality and productivity, and practically eliminating defects caused by power fluctuations. As a result, OEE approaches its potential maximum, annual losses become minimal, and energy independence is ensured under various power supply conditions.

Mathematical analysis

To improve the accuracy of calculations, outages were compared and classified as follows: planned outages (those that match the outage schedules provided by the relevant regulatory authority) and emergency outages, which occur unscheduled. Following the established methodology (Erdős et al., 2020), mathematical matrices of outage frequency and average duration were constructed to identify characteristic seasonal and daily patterns of interruptions across each of the three scenarios. The columns represented months of the year (1 to 12), while the rows denoted hours of the day (0 to 24). From the data array and matrices, the number and duration of outages were extracted accordingly.

To research the similarities and differences in the behavior of simulated power scenarios 1, 2, and 3, several visual tools were employed using well-known methodologies. A histogram (Devore et al., 2021) was created to show the duration and frequency of outages for all scenarios. A box plot was used to analyze outliers, spreads, and medians for each scenario, and a combined chart displaying seasonal outage frequency and average duration with dual y-axes was built (Babura et al., 2018).

Results and discussion

Time losses in the instant noodle production process

The total production time of instant noodles, calculated using formula (1), from the delivery of flour and dry mixes for dough preparation to the completion of the first pallet's movement to storage, amounted to 836 seconds (T_{lead}). The actual time was 971 seconds ($T_{lead\ fact}$ = 836 s + 135 s = 971 s, where 135 seconds represent losses due to additional movements, operator actions, etc.).

The calculated values for production takt time and production cycle time were 0.249 s and 0.289 s, respectively (according to formulas 2 and 3), under stable line operation without power outages. Thus, the actual production speed lagged behind the planned one by 0.04 seconds per unit, resulting in underproduction within a shift. The drop in productivity is primarily recorded at the production stage, which takes 971 seconds instead of the planned 836 seconds (based on formula 1).

In the event of a prolonged power outage, the line must be cleaned, and all products at intermediate processing stages at the time of the stoppage must be discarded (Haes Alhelou, 2019). It is practically impossible to restore the uniformity of the technological process after such a stoppage without complete cleaning and a restart ("cold start"), which results in the loss of both time and raw materials (Pereira et al., 2022). The duration of each operation during the restart of the production line was also manually timed with a stopwatch to obtain accurate and reliable data. The total time for a cold start ($T_{lead\ cold}$) amounted to 2100 seconds (calculated analogously to $T_{lead\ fact}$).

A comparison of $T_{lead\ fact}$ and $T_{lead\ cold}$ shows that $T_{lead\ fact}$ (937 c) < $T_{lead\ cold}$ (2100), meaning that the time required to restart the line exceeds the normal cycle by 2.3 times. Additionally, the downtime during the actual power outage itself can further increase the total loss. Based on this, it can be concluded that the presence and duration of power outages are the key destabilizing factors in production.

In 2024, the planned production time for an average food industry operator (Kudriavtseva, 2025) was 8224 hours, of which 416 hours were allocated for scheduled stops for cleaning and maintenance, conducted weekly. At the same time, an additional 419 hours of unplanned downtime were recorded due to disruptions in external power supply or failures in specific equipment units. As a result, the actual net operating time totaled 7805 hours (according to formula 1).

Overall equipment effectiveness

Losses at the quality control stage amounted to approximately 2.8 %, which is considered an acceptable level for high-volume continuous production in the food industry (Vasylyk, 2018).

In this regard, the impact of emergency and planned power outages on the Overall Equipment Effectiveness (OEE) was simulated.

Based on the research, the calculated performance indicators of OEE components (according to formulas 4-7) are as follows: availability – 94.9 %, performance – 85.6 %, quality – 97.2 %, resulting in an overall OEE value of approximately 78.96 % (Figure 1). This value classifies equipment performance as acceptable (Tsarouhas, 2019), though it still demonstrates a notable potential for improvement. The main losses are caused by unplanned downtime due to power outages.

Pattern and seasonality of outage durations

Based on the above, it follows that due to emergency power supply interruptions, the equipment operates at approximately 79 % of its potential capacity. Further efficiency improvements can be achieved through the implementation of automated monitoring systems and the introduction of backup power systems (Arshad et al., 2021).

The results of the outage classification, calculated using matrices of the number and average duration of outages, are presented in Table 2.

In all three networks, the distributions of outages differ according to the following trends:

- Scenario 1 is the most "stable" (125 hours);
- Scenario 2 combines a large number of short and a considerable share of medium-duration outages (375 hours);
- Scenario 3 features significantly longer durations (616 hours), indicating systematic prolonged interruptions.

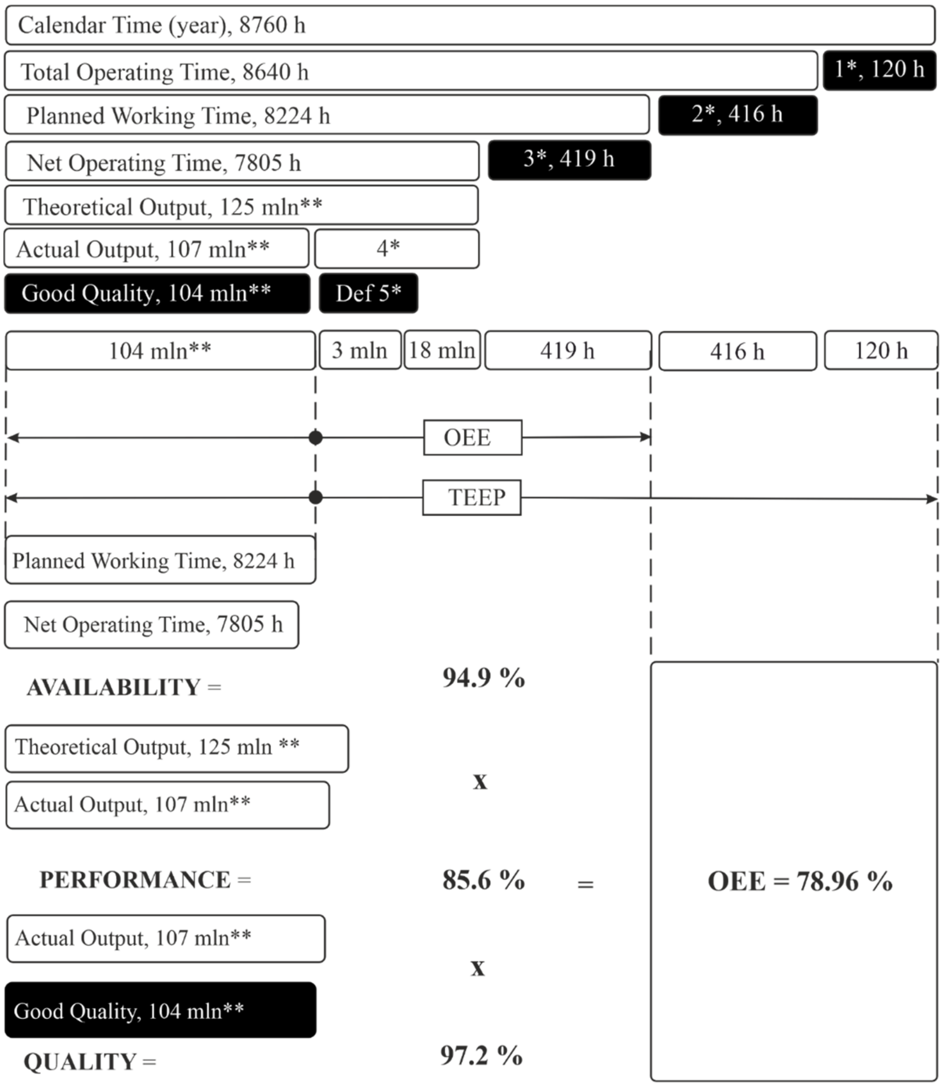

Figure 1. Calculation of overall equipment effectiveness (OEE):
1* – scheduled idle time, 2* – planned downtime,
3* – unplanned downtime, 4* – speed losses,
5* – defects, ** – units

Table 2

Classification of outages into planned (scheduled) and unplanned (emergency)

	Scenario 1	Scenario 2	Scenario 3
Number of Outages			
Total	76	235	161
Scheduled	45 (59.2 %)	132 (56.2 %)	70 (43.5 %)
Unplanned	**20 (26.3 %)**	**54 (23.0 %)**	**61 (37.9 %)**
Duration			
Total	7 429 min (125 h)	22 246 min (375 h)	36 796 min (616 h)
Scheduled, h	67 (54 %)	204 (55 %)	263 (42.9 %)
Unplanned, h	**38 (30.6 %)**	**94 (25.3 %)**	**232 (37.9 %)**

The data obtained from the matrices of outage frequency and average duration, as well as from Table 2, were visualized using a histogram (Figure 2) and a box plot (Figure 3) to simplify the interpretation of results.

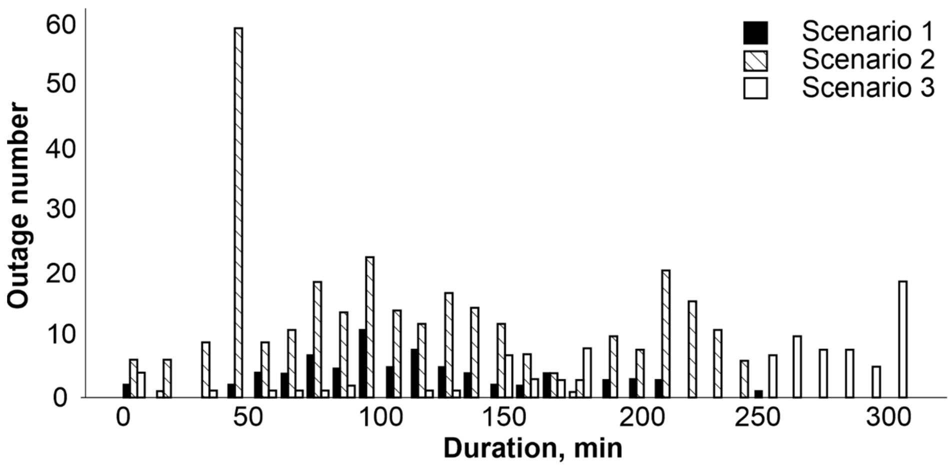

Figure 2. Histogram of outage durations (data is taken every 10 minutes)

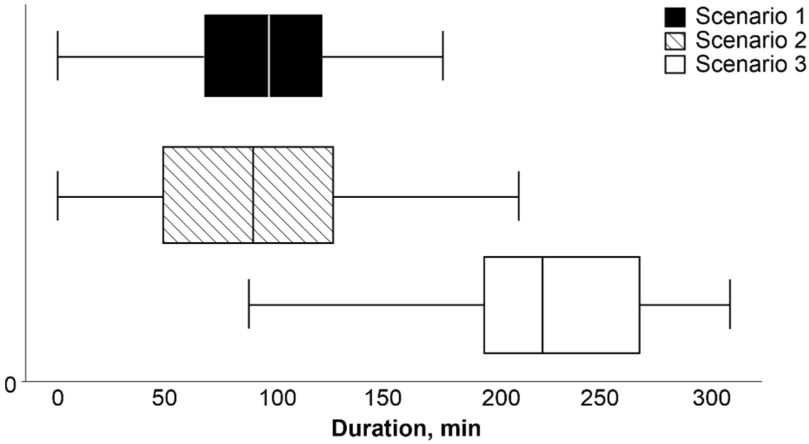

Figure 3. Box plot comparing the distribution of outage durations (data is taken every 10 minutes)

The histogram of outage durations (Figure 2) shows that Scenario 1 and 2 have similar distribution patterns (Devore et al., 2021): the majority of outages last less than 150 minutes, with the frequency peaks of scenario 2 slightly shifted to the right compared to Scenario 1, indicating a general tendency toward somewhat longer downtimes in the second case. In contrast, Scenario 3 is characterized by a distinct pattern with a prevalence of both short outages (up to 100 minutes) and very long ones exceeding 200 minutes.

From the box plot analysis (Figure 3), it can be seen that the medians of Scenario 1 and 2 fall within approximately 70–120 minutes, and their interquartile ranges are relatively narrow, indicating fairly stable short-duration outages.

For Scenario 3, the median (Figure 3) rises to approximately 230 minutes, with interquartile range boundaries stretching from 190 to 265 minutes, demonstrating a significantly wider spread and high variability (Babura et al., 2018), which highlights the instability of the third scenario and the need for further backup power using one of the response scenarios.

After comparing the distribution of outage durations using the histogram and box plot, which provide insight into the wide range and presence of outliers for each scenario, the next step was to analyze the temporal pattern of these events. The chart of the seasonal distribution of the number and average duration of outages by month (Figure 4) shows that the highest number of outages and the longest interruptions are concentrated in the summer months (June-July) and peak winter months (November-January), while in the off-season (September-October, March-April) the indicators practically drop to zero. Scenario 2 records the highest number of outages in July–August, while the duration of interruptions remains relatively stable (≈30-40 minutes). In contrast, Scenario 3 experiences not only high frequency during July-August but also a significant increase in average outage duration (over 220 minutes in August). Scenario 1 shows less seasonality: the number of incidents in July is small (≈33), but the average duration gradually increases, reaching its maximum in November-December.

This indicates a clear seasonal nature of the network's performance and varying loads during warm and cold seasons (Chojnacki, 2023).

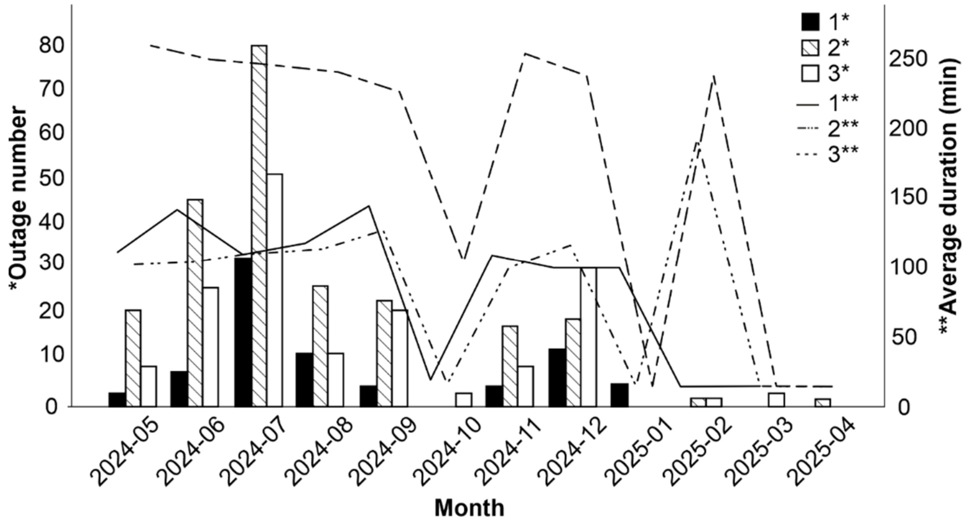

Figure 4. Seasonal distribution chart of outage frequency and average duration by month for Scenarios 1, 2, and 3 respectively (mark 1, 2, 3 on the chart)

Thus, in summer, network loads result in a high number of short outages (especially for scenarios 1 and 2), while scenario 3 is characterized by both frequent and prolonged interruptions. In winter, the effects of cold or precipitation likely lead to less frequent but extremely prolonged outages in scenario 1 and 3. This suggests a focus on preventive measures: during the summer period, rapid elimination of short-term outages should be prioritized, whereas in the cold season, preparation for large-scale long-term downtimes is necessary.

Effectiveness of backup power solutions within operational improvement measures

After performing calculations using the described methods for all selected scenarios (1, 2, 3) and the proposed response options to power outages – “Generator (manual start)” and “Generator + ATS + UPS (instant switching)” – the results were obtained and summarized in Table 3.

For Scenario 1 (short-term outages – 100-125 hours / year), the implementation of a simple generator significantly improves the situation: cycle time is reduced to 0.287 s, and overall equipment effectiveness (OEE) increases to 76.36 %. The comprehensive solution (generator with ATS and UPS) further optimizes operations, reducing the cycle time to 0.288 s and bringing performance and quality indicators close to the standard (OEE = 78.96 %). This indicates full compliance of the backup system with the requirements of stable production cycle support (Van De Ginste, 2022).

For Scenario 2 (medium-duration outages – 350-380 hours / year), a simple generator considerably stabilizes the process indicators: cycle time is reduced to 0.294 s, availability increases to 91.84 %, and performance to 82.37 %. The comprehensive solution ensures the highest stability and efficiency, nearly reaching normative parameters (OEE = 78.96 %). Due to reduced downtime and emergency stops, the production process approaches the nominal cycle (0.288 s).

Table 3

Testing the effectiveness of proposed backup power solutions for simulated scenarios 1, 2, 3

Scenario	Solution	OEE	Availability	Productivity	Quality	Model T_{cycle}, s***
1*	Gen.	76.4	93.78	84.42	96.46	0.287
1*	Gen.++**	78.9	94.9	85.6	97.2	0.288
2*	Gen.	71.8	91.84	82.37	94.92	0.294
2*	Gen.++**	78.9	94.9	85.6	97.2	0.288
3*	Gen.	71.8	91.54	82.06	95.64	0.295
3*	Gen.++**	78.9	94.9	85.6	97.2	0.288

1* – (125 hours / year, 76 outages, 26 % unplanned, average duration 98 min);
2* – (375 hours / year, 235 outages, 23 % unplanned, average duration 91 min);
3* – (616 hours / year, 161 outages, 38 % unplanned, average duration 224 min);
**Generator + ATS + UPS;
***The production takt time and production cycle time are 0.249 s and 0.289 s, respectively, under conditions without power outages.

For Scenario 3 (600 hours / year of outages), generator implementation significantly improves efficiency indicators (OEE = 71.83 %), reducing the cycle time to 0.295 s. However, a notable gap remains compared to nominal parameters. The best results are shown by the comprehensive solution (generator + ATS + UPS), achieving nearly standard indicators (OEE = 78.96 %). The calculated cycle time is reduced to 0.288 s, matching the cycle time under stable conditions.

A comparative analysis of the two scenario results suggests that the optimal solution depends on the intensity and nature of outages (Haes Alhelou, 2019). Under conditions of fewer outages (125 hours/year), a simple generator is a sufficient solution, as its impact significantly improves the main process parameters.

For medium and high outage levels (375-600 hours / year), the most optimal solution is the comprehensive one (generator + ATS + UPS), which minimizes cycle time, productivity losses, and provides the highest production process stability.

Conclusions

1. The research revealed that the optimal solution depends on the frequency, duration, and type of power outages. The higher the intensity of external disruptions, the more comprehensive the solution must be to ensure production cycle stability, maximize equipment efficiency, and minimize unproductive time losses. Solutions proposed to ensure uninterrupted operation and improve the efficiency of the instant noodle production line include the use of a manual generator and a comprehensive solution (generator + ATS + UPS).
2. It was determined that under conditions of short and infrequent outages (short-term outages – 100–125 hours / year), a manual generator reduces the production cycle to 0.287 s and increases the overall equipment effectiveness (OEE) to 76.36 %.

3. In the case of medium-duration outages (350-380 hours / year), the generator reduces the cycle to 0.294 s, while availability and performance increase to 91.84 % and 82.37 %, respectively.
4. It was established that the comprehensive solution (consisting of a generator + ATS + UPS) demonstrated the highest efficiency under long-term outages (over 600 hours / year) in all three scenarios. This solution stabilizes the production cycle at 0.288 s and brings overall equipment effectiveness (OEE) to the target value of 78.96 %. This is especially relevant when a simple generator provides only partial compensation for losses (OEE = 71.83 %, cycle = 0.295 s).

Thus, applying Lean-Thinking tools not only helps optimize resources and reduce production losses but also increases the adaptability of food enterprises to external challenges, particularly under conditions of energy instability. The proposed approach is universal and can be scaled to other technological processes in the industry.

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