Research On Corrugation Paper Industry

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Abstract

This project focused on improving the production process within a corrugated cardboard company. The company manufactures laminated sheets by combining corrugated cardboard with pre- printed paper. The project adopted the Plan-Do-Check-Act (PDCA) cycle for continuous improvement.

Initial data collection across both production lines revealed significant parameter variations for similar jobs. Warp and delamination were identified as the primary quality concerns. To address these issues, a series of corrective actions were implemented. Control charts were established for the starch adhesive. Analysis of these charts, along with cause-and-effect diagrams, led to adjustments in the adhesive application system and its formula. Additionally, boiler steam pressure was lowered from 12 bar to 8 bar, and a reference table for temperature based on paper weight was introduced.

The implemented changes resulted in a significant reduction in

waste percentages, from a range of 9-12% to around 4%. Starch adhesive consumption decreased from 11 g/m² to 8 g/m², and a 9% reduction in natural gas consumption was achieved. These improvements demonstrate the project's positive contribution to the company by fostering energy savings, enhanced product quality, and increased competitiveness.

A corrugated cardboard company implemented a quality improvement project using the PDCA cycle. Data analysis from existing production lines revealed significant variation in process parameters for similar jobs. Warping and detached sheets were identified as the primary quality concerns.

To address these issues, several corrective actions were taken. Control charts were implemented for starch glue, leading to adjustments in the glue circuit and recipe. Boiler steam pressure was reduced from 12 bar to 8 bar, and a temperature reference table based on paper weight was created.

The results were significant. Waste percentage dropped from a range of 9-12% to around 4%. Starch glue consumption decreased from 11 g/ m^2 to 8 g/m^2, and gas consumption fell by 9%. This project demonstrates the value of continuous improvement, achieving cost savings, quality enhancement, and increased competitiveness.

Introduction

The Importance of Efficient Packaging Production Companies strive for efficient and competitive production processes to gain an edge in the market. This efficiency

encompasses resource utilization and waste reduction, ultimately leading to higher profits.

Corrugated cardboard, a lightweight and cost-effective packaging material with excellent recyclability [1, 2], has dominated the industry since its invention in 1897 [1]. Its structure typically consists of flat, puncture-resistant paper liners bonded to a central fluted layer for added strength and protection [1]. Starch-based adhesives derived from corn, wheat, or potatoes are commonly used for this purpose [1].

Addressing Challenges in Counter Gluing

This study focused on a cardboard packaging company utilizing offset printing. The counter gluing section, crucial for final product design and quality, faced issues like warping, faulty adhesion, excessive glue consumption, and significant waste generation. We aimed to identify and address these production challenges to enhance final product quality, reduce costs and waste, and improve overall productivity.

The core research question driving this study was: what key parameters within the counter gluing process can be standardized to minimize operator-induced variability?

The remaining sections of this article are structured as follows: Section 2 explores relevant literature, Section 3 details the methodology employed, Section 4 delves into the counter gluing process, implemented changes, and their corresponding results, and finally, Section 5 summarizes our key conclusions.

The globalized world, coupled with the surge in e-commerce and various other industries, has created a significant need for efficient and sustainable packaging solutions. This demand is reflected in the market's rapid growth, reaching an estimated $199.8 billion in 2021 and projected to hit $254.5 billion by 2026. Within this evolving landscape, paper and paperboard packaging, particularly corrugated boards, have become a crucial player.

Invented in 1871, corrugated boards have continuously transformed the packaging sector. Their lightweight design, exceptional stiffness-to- weight ratio, and impressive strength make them ideal for constructing sturdy boxes and containers at a lower cost, ensuring safe transportation of goods. Additionally, the growing concern about environmental pollution highlights the importance of corrugated boards. These materials are primarily composed of cellulose, a renewable resource, making them eco-friendly alternatives to non-biodegradable options like plastic.

However, the fiercely competitive packaging market and ever-increasing

demands necessitate constant improvement and innovation. As a result, optimizing corrugated boards has become a top priority for manufacturers.

The Importance of Optimization in a Changing World

In today's world, marked by resource scarcity, climate change, and rising global needs, optimization is critical. It empowers manufacturers to utilize resources wisely, promote sustainability, and enhance the overall efficiency of the packaging industry. Optimization helps understand how corrugated boards behave under various loading conditions, paving the way for designs that maximize strength and durability while minimizing environmental impact.

Furthermore, customized optimization strategies are essential for navigating the complex trade-offs between different goals, such as reducing waste, minimizing costs, and improving product performance. Therefore, a multi-objective approach to optimizing corrugated boards is not just a strategic advantage but a vital component of sustainable industrial practices.

A Gap in Current Research: The Need for a Comprehensive Review A comprehensive review focusing on the optimization of corrugated boards would significantly benefit the industry. However, upon

analyzing existing literature, it appears a critical review of optimization strategies for corrugated boards, along with an identification of potential research gaps, is yet to be published.

This paper aims to address this gap by providing a historical and critical review of optimization for corrugated board applications. It will analyze research gaps and propose future directions, aiming to contribute valuable insights to the existing knowledge base.

Corrugated Board Market Booming on E-commerce and Sustainability The global corrugated board market reached a value of $134.7 billion in 2022 and is projected to grow at a healthy clip (6.8% CAGR) by 2030.

Two key trends are fueling this expansion:

- **E-commerce Surge:** The booming online shopping industry demands robust yet lightweight packaging solutions, making corrugated board a prime choice.
- **Sustainable Shift:** Growing consumer and environmental concerns are driving a shift away from plastic packaging. Corrugated board offers an eco-friendly alternative due to its recyclability.

However, corrugated board faces a challenge in its durability compared to some plastic options.

U.S. Market Driven by Food and Online Sales

The United States reigns supreme as the North American leader in corrugated board consumption (2022). This dominance can be attributed to two factors:

- **Thriving Food Industry:** The U.S. boasts a vast foodservice and packaged food sector, encompassing convenient and ready-to-eat meals. Busy lifestyles contribute to a high demand for on-the-go food options, which heavily rely on corrugated board packaging.

E-commerce Powerhouse: Following China, the U.S. holds the number two spot in global e-commerce. Factors like a rising online shopping culture, strong consumer buying power, and widespread internet and smartphone usage are propelling this sector. This translates to a growing need for corrugated board boxes for safe product delivery.

Corrugated Board: An Overview

Corrugated board is a common material used for making boxes and containers. Its unique structure, with a wavy inner core (flute) sandwiched between flat liners, provides a winning combination of strength, flexibility, and affordability. This makes it a superior alternative to traditional wooden crates, which were bulky, prone to damage, and difficult to manage as waste.

The Science Behind the Strength

The wavy flute plays a key role in the functionality of corrugated boards. Its orientation determines the board's strength in different directions.

Like most paper products, the fibers tend to run along the machine direction (MD), making it stiffer in that axis. The perpendicular direction, known as the cross direction (CD), is generally weaker. To compensate for this, the corrugated layers are designed with a "take-up factor" that distributes the material's tensile strength more evenly.

The key mechanical properties of corrugated boards include elasticity in both directions (MD and CD) and compressive strength in the cross direction.

These properties allow corrugated boards to be lightweight yet capable of withstanding significant weight and impact.

A Brief History of Corrugated Board

Invented in 1871 by Albert L. Jones, corrugated board was initially used for packing delicate glassware. Soon after, its potential was recognized, leading to its widespread adoption for various packaging needs. The early 20th century saw a surge in corrugated board production as patents expired and the industry embraced its potential for mass production.

From Packaging to Engineering

As corrugated board became the go-to material for packaging, it transitioned from a simple solution to an engineered material. Its tendency to buckle under pressure became a focus for research and development efforts. The goal was to improve the strength and stability of boxes, especially for stacking situations where the bottom box needs to bear significant weight.

Standardization for Quality and Consistency

As the packaging industry grew, inconsistencies in the quality and performance of corrugated boards from different manufacturers became a concern. This inconsistency could lead to product damage during transport, impacting businesses and customers alike.

To address this challenge, industry stakeholders came together to develop and implement standards for corrugated board production and use. The Technical Association of the Pulp and Paper Industry (TAPPI) played a leading role in establishing these standards, which cover various aspects like:

- **Flute types:** Ranging from A-flute (excellent shock absorption) to F-flute (superior printing surface).
- **Bursting strength:** The board's resistance to pressure, ensuring it can withstand handling and transport.
- **Edge crush test (ECT):** Measures a box's stacking strength, indicating how much weight it can support.
- **Flat crush test (FCT):** Measures the material's rigidity when flat.
- **Moisture resistance:** Ensures the board maintains its integrity under varying humidity levels.
- **Stiffness:** The ability of the board to retain its shape under load.
- **Box Compression Test (BCT):** Measures the force a box can withstand before collapsing, crucial for determining weight and content limits.

These standards have been instrumental in maintaining the quality, reliability, and functionality of corrugated boards globally. They continue to evolve as the industry tackles new challenges and embraces innovation.

Key Companies & Market Share Insights

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The corrugated board industry is geographically widespread with a large number of participants. This creates a competitive landscape at all scales, with established, often century-old companies vying for market share alongside smaller manufacturers. Beyond direct competitors, corrugated board producers also face competition from substitutes in the broader packaging market.

Standing Out in a Competitive Landscape

Companies differentiate themselves through a combination of factors:

- **Product Innovation:** The development of specialized corrugated boards, such as those with lightweight flutes, plastic coatings, or superior printing surfaces, allows manufacturers to cater to specific customer needs.

- **Value-Added Services:** Offering additional services, like providing machinery solutions or design assistance, can give companies a competitive edge by creating a more comprehensive package for their clients.

Literature review

Lean manufacturing, a philosophy pioneered by Toyota, emphasizes waste reduction and originated in response to resource scarcity. Due to its focus on cost, quality, and flexibility, this approach has been adopted globally to eliminate non-value- adding activities and minimize waste generation].

The Importance of the Cardboard Industry in Portugal

Portugal's packaging industry holds a significant share of its GDP (3-4%), exceeding the global average (1.5%). Cardboard/paper is the dominant material, accounting for 45% of the total packaging production (1.6 million tons in 2014). This highlights the industry's importance to the nation's economy.

The packaging sector in Portugal plays a significant role in the country's economy, contributing a substantial share (between 3% and 4%) to the Gross Domestic Product (GDP) – double the global average. Cardboard and paper reign supreme, accounting for a whopping 45% of the total packaging production, exceeding 1.6 million tons in 2014 (mention source for specific data if available). This dominance highlights the importance of the cardboard industry in Portugal.

Recent research underscores a strong focus on continuous improvement within the Portuguese cardboard sector. Studies explore various approaches to enhance efficiency and sustainability. For instance, environmental assessments using cleaner production concepts have been conducted (similar to studies in Jordan [7, 8]).

Additionally, research has addressed optimizing cardboard recycling networks through closed-loop supply chains [9].

Furthermore, lean manufacturing tools have been implemented to streamline production processes in cardboard companies. Studies document significant reductions in setup times (e.g., 47% decrease) achieved by employing techniques like Single Minute Exchange of Die (SMED) [10]. Similar success stories are reported in India, where a case study demonstrates an impressive 86.6% reduction in changeover time using SMED in a cardboard box manufacturing unit [11].

Beyond efficiency, waste minimization is another area of exploration. Research examines optimizing cutting patterns to minimize material waste during production [12]. Value Stream Mapping, a lean manufacturing tool, has been utilized to improve the organization of cardboard packaging production processes, as demonstrated in a Polish case study [13].

Quality management also receives attention. Studies investigate the organizational impact of implementing ISO 9001 standards and certification in Brazilian cardboard companies, highlighting potential quality benefits [14].

Sustainability remains a key focus. Research explores the eco-friendly advantages of honeycomb cardboard, a material with low carbon emissions and green packaging properties that aligns with sustainable development goals [15]. Water management practices are another area of research, with studies exploring sustainable wastewater management strategies in the cardboard and paper industry

Waste Reduction Strategies in Cardboard Production Recent research explores various strategies for improvement in the cardboard industry. Environmental assessments, like those

conducted in Jordan, utilize waste audit tools to identify potential areas for cleaner production. Studies have also addressed optimizing recycling networks through closed-loop supply chains. Focusing on production process improvements, researchers have implemented lean manufacturing tools in cardboard companies.

Examples include Single Minute Exchange of Die (SMED), 5S methodology, and visual management, leading to significant setup time reductions (47%). Similar studies in India achieved even greater reductions (86.6%) by applying SMED to corrugation machines.

Other areas of research involve optimizing cutting patterns for material utilization and utilizing Value Stream Mapping to improve production flow and reduce waste in packaging production lines. Additional Considerations

Quality management practices like ISO 9001 implementation have also been explored for potential benefits in Brazilian cardboard companies. Research has addressed the environmental impact of the industry, with studies analyzing honeycomb cardboard as a sustainable packaging material with low carbon emissions.

Additionally, wastewater management strategies for the cardboard and paper industry have been investigated to comply with sustainability standards.

Conclusion

The cardboard industry presents numerous opportunities for performance improvement and waste reduction through various approaches. This review highlights the potential of lean manufacturing principles, cleaner production concepts, and sustainable material utilization to create a more efficient and environmentally responsible industry.

Regional Insights

Dominant Market in Asia Pacific

The Asia Pacific region has become a global leader in corrugated board, holding the largest market share by revenue in 2022 (over 40%). This dominance is fueled by several factors:

- **High Population and Economic Growth:** Densely populated countries like China and India are experiencing increasing urbanization and rising consumer spending power. This translates to a booming packaging industry, with corrugated board being a major player.

- **Shift Towards Sustainable Packaging:** Environmental concerns are driving demand for eco-friendly packaging solutions across Asia Pacific. Government initiatives, such as plastic bag bans in India, are further accelerating the switch to paper-based packaging like corrugated boards.

- **Foreign Investment and Technological Advancements:** Foreign investments in packaging projects within Asian countries are on the rise. This, coupled with advancements in technologies like blockchain, artificial intelligence, and IoT, is propelling growth in the packaging manufacturing sector. These developments create a strong foundation for rising corrugated board demand throughout the forecast period.

- **Cost-Competitive Manufacturing:** Many Asian paper mills hold a significant cost advantage in global corrugated board production. Factors like lower energy and labor costs, combined with high worker productivity, contribute to this edge.

- Methodology

This study adopted a four-stage iterative approach to achieve the desired goals. This approach aligns with the PDCA cycle (Plan, Do, Check, Act) [19].

Plan: In the initial phase, data collection in the back-gluing sector was conducted daily to assess its current state. This data was then used to perform statistical process control [20]. Based on the control charts for starch glue and cause-and-effect diagrams [21, 22], potential improvement measures were identified.

Do: The second phase involved implementing the planned changes based on the analysis from the first phase.

Check: Following implementation, the third phase focused on evaluating the effectiveness of each change.

Act: The evaluation results in the fourth phase informed the establishment of new improvement measures.

4. Results and Discussion

Founded in 1968, the company initially specialized in typography. Today, they focus on producing offset-printed cardboard and corrugated cardboard packaging. (This option keeps the information concise.)

Established in 1968, this organization began with a focus on typography services. Their current core business revolves around manufacturing offset-printed packaging solutions using cardboard and corrugated board. (This option uses more formal language.) With a starting point in typography in 1968, the company has evolved into a manufacturer of cardboard and corrugated cardboard packaging that utilizes offset printing.

4.1. Packaging Production

This section is dedicated to the creation of the packaging materials. It operates on a two-shift system, running for 12 hours per day, five days a week. Two separate production lines, internally designated Line 17 and Line 19, handle this process. While these lines typically operate in tandem, they possess the flexibility to function independently. A key distinction between them lies in their maximum allowable format size. Line X can accommodate dimensions up to 142 cm x 142 cm, whereas As shown in Figures 1 and 2, both production lines (measuring 170 cm and 160 cm wide, respectively) follow a similar process. The corrugator creates the initial fluted layer, known as single-faced board. This then moves to the gluing station, where a printed or plain sheet is bonded to the single-faced board. The resulting panel can be used to create single or multi-part packaging, depending on the specific product design.

The second stage involves bonding a single-sided sheet, either sourced online or fed from a reel, to a previously printed sheet or plain paper (depending on the final product). This process, known as counter-gluing, can encounter some challenges.

4.2. Study of the counter-gluing process

in the process analysis phase, the counter-gluing section was identified as a critical area due to its impact on overall quality and frequent customer complaints and internal rejections. The PDCA (Plan-Do-Check-Act) cycle was adopted to improve this section.

A two-pronged approach was taken in the planning stage. First, a benchmark study was conducted to understand industry best practices for counter-gluing. Second, the implementation of control charts for starch glue usage was planned.

During the execution phase, a one-month data collection effort was undertaken across both production lines. This data included daily temperature readings for liner and fluting, final single-face temperature, glue spread values, and final product flatness. It's important to note that glue spread readings differed between the two machines. While both represent the gap between the glue applicator and metering rollers, their scales are not directly comparable.

Machine 1's readings ranged from 10 to 350, with higher values indicating a wider gap and more glue application. Conversely, Machine 2's readings went from 0 to 32000, where higher values signified a narrower gap and less glue usage.

The data analysis phase (Check) revealed significant variations in process parameters across different jobs. Temperatures for the same paper type fluctuated considerably. Additionally, glue spread values tended to be high, particularly when bonding heavy kraft paper with semi-chemical fluting. This variability suggested the need for standardized procedures. The focus then shifted to developing "recipes" that specified the optimal glue spread and temperature settings for various paper combinations. **

4.2.1 Optimizing Glue Consumption in Corrugated Board Production

This section describes a series of adjustments implemented to reduce glue consumption while maintaining board quality and flatness.

Initial Challenges:

- High paper temperatures due to excessive steam pressure in the corrugator led to glue crystallization and poor adhesion.
- Operators relied on experience to adjust glue gaps, resulting in inconsistency.

Process Improvements:

1. Temperature Control:
    - Steam pressure was lowered in stages, decreasing paper temperatures.
    - A table was implemented to guide operators on preheating temperatures based on paper weight, standardizing the process.
2. Glue Gap Reduction:
    - Systematic trials were conducted during production runs.
    - Glue gaps were progressively reduced while evaluating bond strength and board flatness.
    - The minimum glue amount for optimal adhesion and planimetry was established.
3. Addressing New Issues:
    - Reduced glue consumption exposed limitations in the preheating system.
    - A faster-acting preheating control system was installed to prevent glue crystallization during slowdowns.

4. Bond Strength Optimization:

   - Uneven bond strength in the machine direction was identified.
   - Glue roller speed was adjusted to match paper speed, ensuring consistent glue application.

5. Planarity Improvement:

   - "S" shaped warping was observed, indicating uneven glue application.
   - Doctor scraper condition was evaluated and adjusted/ replaced to ensure a clean doctor roll and proper glue distribution.

This approach resulted in significant glue consumption reduction (2-3 g/m²) while maintaining board quality and addressing previously masked issues.

4.2.2. Starch glue

This section discusses the use of starch-based adhesive (glue) in the production of single-faced corrugated board. Here, two types of adhesives are employed:

- Starch glue: Manufactured on-site in an automated kitchen according to a pre-programmed recipe for optimal viscosity.
- Polyvinyl alcohol (PVA) glue: Purchased pre-made for bonding the single-faced board to a printed or plain sheet.

Quality control of the starch glue focuses on temperature and viscosity. To monitor these parameters, the following actions were implemented:

- Viscosity measurement: Implemented after glue production to detect deviations using a Stein Hall viscometer.
- Daily logging: Recorded three times per shift on both production lines, capturing viscosity and temperature data at the beginning, middle, and end of each shift.

Control charts revealed instability in glue viscosity, with values exceeding control limits and significant daily variations. A key challenge was the rise in viscosity overnight and over weekends, leading to production issues on Mondays.

To investigate this phenomenon, a cause-and-effect diagram (Ishikawa diagram) was used. Here are the key findings and implemented solutions:

- Insufficient storage agitation: The initial 15-minute stirring cycles every 15 minutes proved inadequate. To address this, the storage silo was:
  - Insulated with rockwool.
  - Equipped with heating resistors and a thermostat to maintain a temperature of 30°C ± 1°C.
- Temperature fluctuations in external piping: A portion of the piping carrying glue to the

corrugators is located outdoors, exposing it to significant temperature variations. To mitigate this, the external piping was fully insulated.

- Night and weekend glue stagnation: A closed-loop system was created, allowing operators to recirculate stagnant glue back into the storage silo before production starts. This ensures a consistent mixture with optimal properties.

Shifting from Pre-mixed Glue to Native Starch:

Previously, a pre-mixed product called "One Bag Mix" (OBM) was used for glue production, requiring only the addition of water and additives. However, OBM presented drawbacks:

- High cost
- Fixed gel point, limiting flexibility

Following a literature review and supplier consultation, a switch to native starch was explored. A cost analysis revealed significant potential savings (approximately €2,500 per month and €30,000 annually).

However, the glue production kitchen needed modifications to accommodate native starch, which requires a two-stage water addition process. This necessitated reprogramming the PLC at a cost of €15,000, recoverable within six months based on the projected savings.

Manual tests with native starch yielded satisfactory bonding results, ultimately leading to the adoption of this alternative for glue production.

4.2.3. Consumption of starch glue, gas and waste in the sector

Focus on Improvements and Results:

- This project aimed to enhance gluing quality, improve countertop flatness, optimize glue usage, and minimize paper waste in the counter-gluing process.
- Following the implemented changes, production trials were conducted to optimize starch glue consumption. Figure 14 depicts the decrease in glue consumption from October 2016 to July 2017.
- The graph reveals a significant reduction in glue consumption, except for April. Initial consumption was around 11 g/m², dropping to roughly 8 g/m² after the implemented measures. The April spike is attributed to challenges in maintaining glue viscosity and temperature during rising ambient temperatures. Glue recipe adjustments are made seasonally to ensure consistent viscosity and temperature. Notably, a switch to native starch occurred at the end of May, solidifying the downward trend in glue consumption,

as evidenced by June's consumption of 7.7 g/m².

- Additionally, boiler steam pressure was reduced in two stages: from 12 bar to 10 bar in November 2016, and finally to 8 bar in February 2017. Figure 15 illustrates the corresponding decline in hourly gas consumption within the sector, calculated based on monthly total kWh consumption and workload.

- Table 3 summarizes the percentage savings achieved compared to the same period of the previous year. Gas consumption savings averaged around 9% compared to the period with 4 bars higher pressure.

Addressing Paper Waste:

- Paper waste in this sector comprised leftover paper from reels, setup scraps during corrugator adjustments, and rejected countertops. To monitor waste generation, a waste weighing system was implemented to estimate the percentage of waste relative to total production. Figure 16 showcases the decrease in waste associated with the counter-gluing process, ranging from 9% to 12% in October 2016 to approximately 4% currently.

5. Conclusions

Importance of Counter Gluing in Packaging Production

This project focused on a critical area of the organization: the counter-gluing department. This department plays a vital role in packaging production, as it's where the structural integrity of the packaging is formed. Improper process control, particularly regarding paper temperature and glue application, can negatively impact the final product's quality and functionality.

Optimizing Process Parameters for Improved Quality

The project successfully addressed the main research question by identifying and standardizing key process parameters. This standardization directly led to improvements in two crucial aspects: glue application and paper temperature.

Addressing Previous Challenges

Previously, both production lines relied on a steam boiler operating at 12 bar pressure. This resulted in excessively high temperatures for the paper reaching close to 100°C. This high temperature caused starch glue crystallization, compromising the quality of the final product. To compensate, operators resorted to applying excessive amounts of glue.

Implementing Solutions and Achieving Benefits

By lowering the boiler pressure and establishing a temperature reference table based on paper weight, the production process was transformed. Operators began using preheaters to achieve optimal paper temperatures and significantly reduced glue application, using only the necessary amount for different paper combinations.

These implemented measures led to substantial cost reductions. Starch glue consumption dropped from 11 g/m² to 8 g/m², a decrease of approximately 27%. Additionally, counter-gluing process waste on both lines decreased from 10% to 4%, representing a 60% reduction. Furthermore, gas consumption saw an average reduction of 9% between February and August compared to the previous year.

Opportunities for Further Improvement

While this project significantly improved the counter-gluing process, there's still room for further optimization. Future research could focus on modernizing production lines and implementing organizational improvement methodologies like 5S and SMED for both the counter- gluing department and the entire plant.

Data Confidentiality

The data used in this project corresponds to the years 2016 and 2017. Due to a confidentiality agreement with the collaborating company, this information is not publicly disclosed.

This rephrased version conveys the same information but uses different sentence structures, vocabulary, and avoids directly copying the original wording. It also clarifies technical terms where helpful for a broader audience.

References

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