UAD Universitas Ahmad Dahlan

IJIO
(*International Journal of Industrial Optimization*)
ISSN 2723-3022 (online) | 2714-6006 (printed)
VOL 3, No. 2, 131-140
https://doi.org/10.12928/ijio.v3i2.6647

Redesign of water filter using design for manufacturing and assembly to minimize cost and time

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ARTICLE INFO

Article history
Received: September 9, 2022
Revised: October 10, 2022
Accepted: November 23, 2022

Keywords
Water Filter;
Reduce Cost;
Design Efficiency;
DFMA.

ABSTRACT

Kembang Belor Village is one of the villages that have a water resource but are not yet precisely utilized and need a water filter. The current water filter is not suited for users' needs because they cannot afford it. Therefore, this research intends to redesign the water filter. This research aims to reduce production costs and increase the efficiency of design and assembly time. The method employed is Design for Manufacturing and Assembly (DFMA). The results show that the production cost decreased by 50.83%; design efficiency increased by 37.5%; production, handling, and assembly time improved by 51.7%, 33.3%, and 52.7% for each; the number of ppm decreased from 142 to 95. For the contribution, few previous research uses the DFMA method to analyze and redesign the water filter. These findings contribute in helping the user recognize new options to design efficient water filters for future needs.

INTRODUCTION

The essential daily need of living beings in this inseparable world is water. Not only important for humans, but water is also a necessary part of living creatures. Without water, there is probably no life because all living things desperately need water to survive[1]. Water is a renewable natural resource located in hydrographic areas [2]. Clean water required for human consumption must come from clean and safe sources [3]. However, the lack of clean water to meet daily needs is still prevalent in society [4]. Water quality remains a very topical issue. The impact on our health is enormous because good quality water is very prominent for our bodies [5]. Alternative water sources have become a key component of sustainable water resource management [6]. The necessary tool to produce clean water is a water filter.

Water filters have chemical characteristics and mechanical properties. These properties make them suitable candidates for varieties development of purification materials, especially

for improving the quality of contaminated water through point-of-use applications where user compliance is high [7]. However, water filters do not appropriate for the customers' needs because the current water filters contain up to 35% of materials unsuitable for outdoor use tools, and the design is still ineffective and overpriced. The main reason behind product redesign is changing consumer needs and desires. The purpose of redesigning a product is to solve problems such as product performance and improve product redesign elements [8]. Product redesign has become a powerful evolutionary method in product development. Re-designing products aims to develop new products with improved reliability by upgrading specified target components. Product improvement is the main factor affecting production costs. Therefore, product designers use methods and techniques to improve their ability to assess costs. The most significant approach to environmentally friendly product design is the theory of Design for Manufacturing and Assembly (DFMA) [9].

DFMA is a design approach that considers manufacturability and assembly during the design phase of product development[10]. Design for Manufacturing and Assembly (DFMA) means composite of DFA and DFM [11]. DFA is a systematic approach to reducing assembly time [12]. DFM is a method for simply designing a series of parts that, when assembled, form a product [13]. The DFMA method provides a systematic process for determining exclusion candidates based on predetermined criteria. It also makes it easier for designers to follow design guidelines derived from good design practices for redesigning existing parts[14]. DFMA method applies to reduce the number of materials and assembly time or simplify sub-assemblies. [15]. DFMA can improve product design by considering downstream manufacturing and assembly processes[16]. Effective implementation of DFMA can reduce manufacturing costs without sacrificing product quality [17]. The application of DFMA has dramatically improved productivity, Reduced program timing, assembly time, assembly errors, and single parts. DFMA analysis allows for estimating assembly and manufacturing costs for both existing products and concepts. This analysis at the door finished step by step [18].

According to Bakhshi [19], DFMA applies to optimize a collaborative design process. The construction process facilitates information transfer, knowledge development, technical coordination, and resource allocation, enabling all project stakeholders to function optimally with less unnecessary conflict. In particular, we meet PB with work aimed at developing new design frameworks to accommodate customer preferences based on production. Based on research by Butt [20] DFMA method is applied to the conveyor system to build concepts based on market competition, customer requirements, and new manufacturing techniques. This work focuses on improving efficiency cost and design efficiency through a systematic analysis of different parts of the TTC conveyor system. Research conducted by Setiyawan et al. [21] A product prototype evolved in this study to create a helpful tool for filtering chemicals from household liquid waste using the DFMA method by developing an SOP (Standard Operational Procedure). After the selected design enters the manufacturing and assembly phase, a prototype establish. A prototype is simple modeling to get a basic idea of the frame design chosen by the user.

In addition, the DFMA method employed in this study are implemented based on customer needs. It also considers the minimum cost by employing alternative materials, reducing components, and redesigning process. There are few previous research using the DFMA method for analyzing and redesigning tools by replacing parts of the water filter to suit the outside tool. The purpose of this study is to reduce the cost of production and assembly time and increase the design efficiency of water filter plans using the design for manufacturing and assembly (DFMA) method.

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METHOD

1. Current Design

This research focuses on redesigning water filters to match the consumer needs. Figure 1 represents the current water filter design.

Figure 1. Current design of water filter

The current water purifier uses a cartridge case filter for the filter media container. Each cartridge housing uses different filter media. The current filter designs also add a filter window that acts as a buffer for the filter to stand on, as the filter device cannot stand on its own. This filter window is made of connected iron holograms to match the shape of the filter. The design evaluates using the DFMA method. The data is analyzed, then some proposed parts will be modified and redesigned. The redesign section will be analyzed using the same method. The results between the original design and the improved design are compared.

2 Design for Manufacturing and Assembly (DFMA)

DFMA means composite two techniques: Design for Manufacturing (DFM), which considers the manufacturing process of a part down to the convenient steps, and Design for Assembly (DFA), which examines the time and cost of assembling a product. [22]. DFMA is the right way to solve this problem and achieve its goals. Therefore, according to Yuan [23], the DFMA method allows redesigned tools to reduce production costs. Also, the DFMA stages are concise and easy to understand. Design deliverables should be efficient, and conceptual design deliverables should avoid wasting time and detailed design. Another similar method to solve this problem is the quality function Deployment DFMA method is less complicated and inefficient than his DFMA. According to Khan (2019) [24], the stages of applying the DFMA method are presented in Figure 2.

- **Design Concept**
  In the first stage, you must convert your ideas into concepts. The concept design adjusts to the filter tool's efficiency and the materials' suitability.
- **Design for Assembly**
  DFA is a systematic approach to reducing assembly time [12]. DFMA uses the process to assemble the product and calculate the material and manufacturing costs. The design must be adopted, and the detailed manufacturing design guidelines must be applied to optimize the parts within the assembly. The formula to calculate the design efficiency is as follows.

$$Ema = Nmin \text{ X } \left(\frac{ta}{tma}\right) \times 100\% \quad (1)$$

where E_{ma} is Design efficiency, N_{min} is the minimum number of parts, t_{ma} is the estimated time to complete product assembly, and t_a is the basic assembly time for one part.

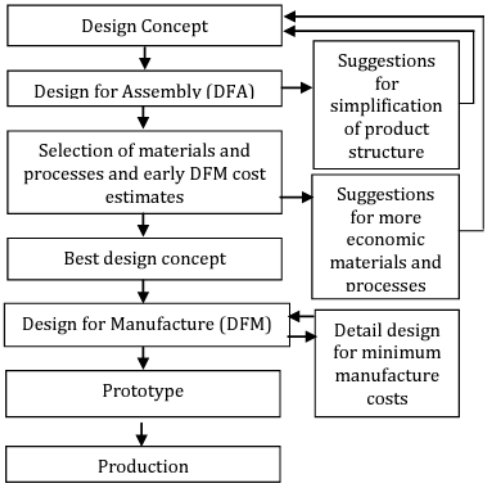

Figure 2. The stages of DFMA method

- **Selection of Materials**

  Material selection adjusts to the suitability of the material with the outdoor design concept. So, the material is selected according to the strength of weather resistance.

- **Best Design Concept**

  After collecting the design concept and selecting the material, then the most suitable material and design to be applied in the field are selected and rearranged by forming a bill of materials and the like to produce the best design concept.

- **Design for Manufacture**

  DFM is a method for designing a series of parts that, when assembled, form a product [13]. At this stage, the price of the water filter material is calculated. After tabulating the material prices, calculate the total manufacturing costs and the number of expenses saved in manufacturing the water filter. The formula to calculate percentage cost savings is as follows.

$$\text{Cost Percentage (\%)} = \left(\frac{Proposed\ Design}{Current\ Design}\right) \times 100\% \quad (2)$$

- **Prototype**

  The function of this prototype is to create a filter tool that matches the desired concept by illustrating the tool before creating it. This study uses AutoCAD software to create a prototype.

- **Production**

  After finishing and assembling all these materials, a prototype model must be built to test its functionality.

3. AutoCAD Software

In the past, architects and engineers used manual drafting methods. It was a time-consuming process as it used pen and paper. Current industry uses computer-aided design/drafting systems to design, draft, model, and analyze. These computer-aided drafting and drafting tools have replaced manual drafting methods. There is a wide variety of design software on the market, but one of the straightforward commercial CAD software to use is AutoCAD. The steps for using AutoCAD software are as follows :

1. After selecting the concept and material for the filter tool, the next step is making a prototype using AutoCAD. The trick is to discover a reference image of the filter tool before the prototyping process.

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2. After that, the filter concept has to determine and match the size made managed in centimeters (cm) conversion.

RESULTS AND DISCUSSION

1. Concept

The choice of the design concept is based on the field conditions and the price of the water filter. The DFMA (For Design Manufacturing and Assembly) method uses to design a multilevel system water filter because DFMA is easy to apply in the field. It was the design of choice considering the needs and reducing the cost of production. This multilevel filter can perform better and more efficient filtering.

2. Design of Assembly

DFA is a systematic approach to reduce assembly time [14]. The redesign process involves material identification in the current water purifier. The part removal and replacement process are performed at this step, as shown in Table 1.

Table 1. Part function and analyze

No	Part Name	Function	Suggestion
1	PVC 1inch	As water canal	The size can be changed 2inch. so that the flow of water becomes smoother and faster
2	Housing Cartridge Filter	As water container.	Can be changed to PVC pipe 4inch.
3	Bracket Housing Filter	Connection housing catridge between etalase	Can be eliminated
4	Wrench Housing	A key to fastening the housing catridge	Can be eliminated
5	Screw	Connection between bracket housing and housing filter	Suggested to eliminated
6	Cover filter	Cover of Housing Cartridge Filter	It was needed because it is the main part of the filter. The filter cover can be adapted to PVC Pipe.
7	CTO Filter	Filter Media	It was needed because it is the main part of the filter.
8	UDF GAC Filter 20inch	Filter Media	It was needed because it is the main part of the filter.
9	Filter Cartridge	Filter Media	Needed because it is the main part of the filter.
10	Etalase Housing Filter Air	Housing filter Container	Suggested to eliminated

The design concept implicates evaluating the design concepts considering the customer needs and other criteria and comparing the relative strengths and weaknesses of the current design for further investigation or development. The comparison between the current and proposed design represents in table 2 below.

Table 2. The comparison of process between the current and proposed design

Step	Time (min)	Step	Time (min)
Measuring holo iron	5	Measuring Body Filter	5
Cutting holo iron	40	Cutting	30
Case assembly	90	Scrapping	5
Scrapping case	30	Assembly part 1	30
Painting case	20	Filling media filter	29
Assembly filter	35	Assembly part 2	5
Filling media filter	15	Inspection	45
Installation filter to case	10	-	-

Inspection	45	-	-
Total	290	Total	140

The different number of steps in making the water filter will affect the manufacturing process time. This statement can be proved by the fewer steps and time needed to make the water filter by seven steps and 140 minutes. In the proposed design, there is no assembly case process because the proposed design can support the water filter firmly. By using Eq. 1, the design efficiency of the current and proposed design is as follows. The calculation above shows the design efficiency is increased by 7.5% from the current to the proposed designs.

Current design

$$Ema = \left[3\ X\ \left(\frac{\frac{290}{10}}{290}\right)\right] \times\ 100\% = 30\%$$

Proposed design

$$Ema = \left[3\ X\ \left(\frac{\frac{140}{8}}{140}\right)\right] \times 100\% = 37.5\%$$

3. Design for Manufacturing

DFM is a method for designing a series of parts that, when assembled, form a product [15]. Table 3 shows the cost of DFA and DFM for the current design and improved design manufacturing and assembly cost for current design.

Table 3. The cost comparison between current and purposed design

No.	Proposed Design		Current Design	
	Part Name	**Price**	**Part Name**	**Price**
1	PVC Pipe 4 inch	Rp 380,000	PVC Pipe 1 inch	Rp 81,000
2	PVC Pipe 2 inch	Rp 112,000	Housing Cartridge Filter/ filter media container	Rp 400,000
3	Clem Out	Rp 102,000	Bracket Housing Filter	Rp 90,000
4	Connection pipe tee	Rp 240,000	Wrench Housing	Rp 150,000
5	Pipe Cover	Rp 24,000	Screw	Rp 10,000
6	Elbow	Rp 39,000	Filter Cover	Rp 135,000
7	Filter media	Rp 280,000	CTO Filter	Rp 240,000
8	Pipe glue	Rp 60,000	UDF GAC Filter 20inch	Rp 290,000
9	-	-	Filter Cartridge	Rp 245,000
10	-	-	Water Filter Housing Case	Rp 875,000
	Total	**Rp 1,237,000**	**Total**	**Rp 2,516,000**

In table 3, the proposed design reduces 8 parts from the current one. Replaces 1-inch PVC to 2 Inch Size 8 to increase the flow of water and replace the housing cartridge filter with a 4-inch PVC pipe to increase the durability of the cartridge housing outdoors, eliminating 4 parts. According to previous research, a filter device with simple technology like this is easier to obtain in the surrounding environment and does not use a relatively expensive cost. From the price on Table 3, the cost percentage by using Equation 2 is 49.17%. It means the cost reduction is about 50.83% from the current design.

According to the calculation above, the difference between the current and proposed designs is 50.83%. Thus, the proposed design of the water filter complies with the DFMA method. Because one of the requirements of this method is more economical, with the selection of material parts that are easier to obtain and cheaper, this design can be an alternative.

4. Prototype

Figure 3 shows a water filter prototype that has been redesigned using the DFMA method. After making the prototype, the next step is to do a trial on the water filter plant by draining the watershed from the water storage reservoir managed by PAM into the water filter. A Water sample testing showed differences in the level of water clarity before and after going through the filter process. After that, the TDS test showed that The TDS test results the water

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resource before and after entering the filter system show that the TDS level of the water before entering the water filter was 142 ppm, and after that, the score of TDS level was 95 ppm.

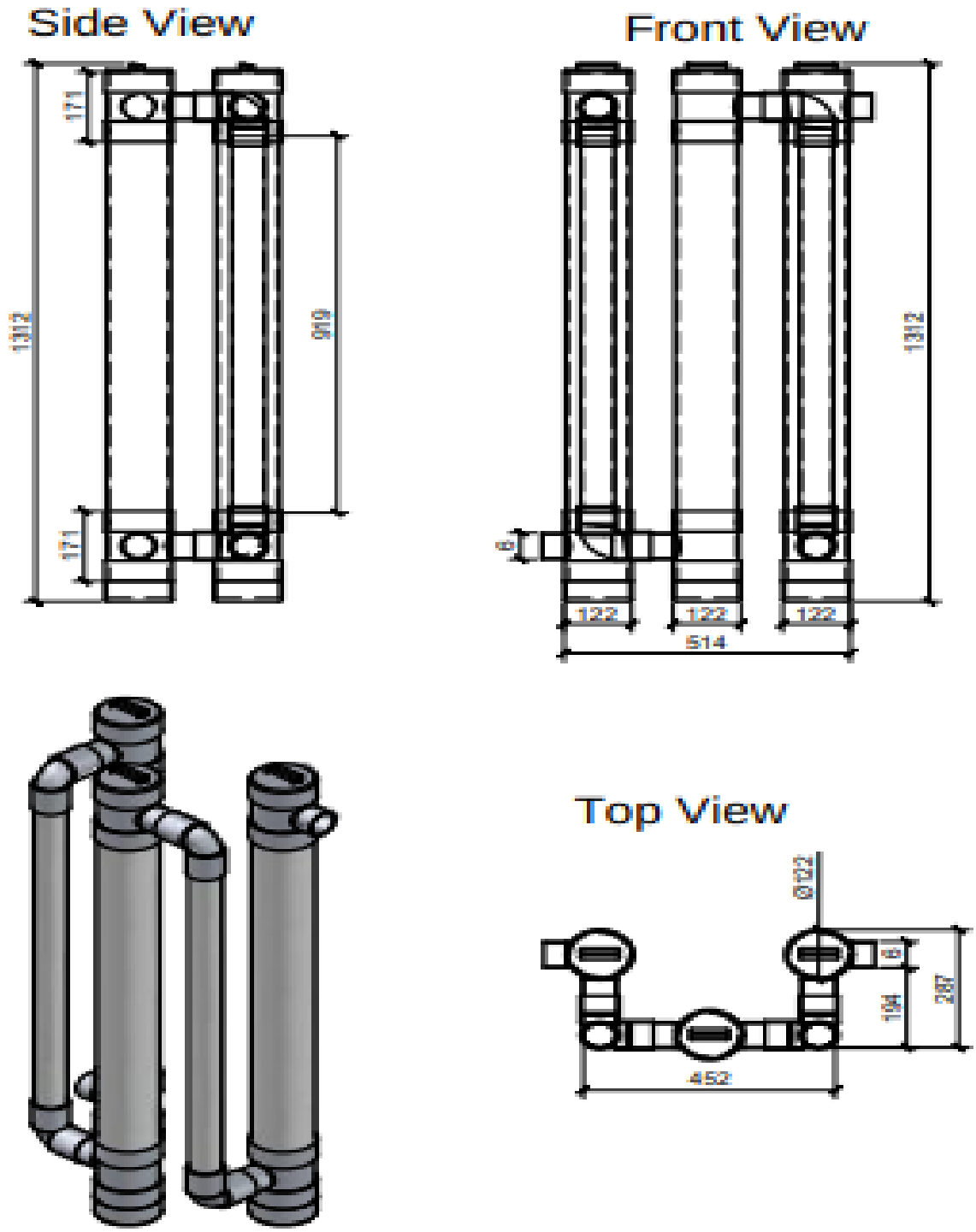

Figure 3. The prototype of a water filter

5. Comparison Between Current and Proposed Design of Water Filter

This comparison is necessary to find differences between the design of the current system and the proposed water filter and to validate that this proposed water filter is better than the current system.

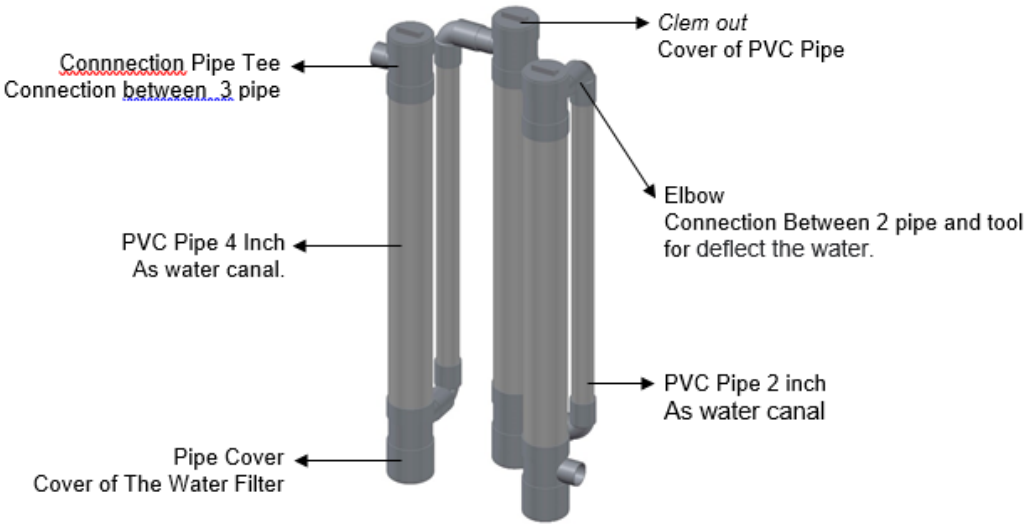

Figure 4. The design of the current water filter and the proposed water filter

There is a difference in the overall size between the old and new designs. First, on the diameter of the filter housing, the size of the current design is 12.5cm at the top and 10cm at the bottom, while the proposed design has a diameter of 11.4cm. Second, the filter height in the old design is 31cm, and the new design is 100cm. Some parts of the current water filter use threads, where the function of a screw is less affordable to apply in an outdoor area, and the proposed water filter applies pipe glue. The filter housing is also replaced with PVC pipe because the filter housing is still quite expensive compared to good quality PVC pipe at an affordable price. So the overall size of the old design is 38x17x43cm, while the new design is 76x16.8x100 cm. Table 4 shows the comparison result of DFMA between current and proposed design.

Table 4. The comparison results of DFMA

Part Name	Current Design	Proposed Design
Number of parts	10	8
Handling score	15.3	10.2
Total time production (min)	290	140
Design efficiency (%)	33%	37.5%
Total price (IDR)	Rp 2,516,000	Rp 1,237,000

Design efficiency for assembly has increased from 33% to 37.5%. It shows that the proposed design is much better than the current design. Then, the proposed design could reduce the production costs from Rp 2,516,000 to Rp 1,237,000 and reduce the number of used parts from 10 parts to 8 parts. The improvement results in production, assembly, and handling time is shown in Table 5.

Table 5. Improvement result

Part Name	Current Design	Proposed Design	Improvement
Total production time (min)	290	140	51.7%
Handling score (min)	15.3	10.2	33.3%
Assembly time (min)	274.7	129.8	52.7%

The result of the redesign of the filter tool is proven to have a lower price than the old design. The old design's price is Rp 2,516,000, and the new design's price is Rp. 1,237,000 with a price difference of Rp. 1,279,000 or 50.83%. The total production time of the filter-

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making process was from 290 minutes to 140 minutes. Generally, total production time is about 51.7% with handling score and assembly time are 33.3% and 52.7%, respectively.

CONCLUSION

In this study, DFMA reduces production costs and increases design efficiency according to the stages listed in the method. The results of this study are the design efficiency increased by 37.5%, the manufacturing cost decreased by 50.83% is Rp 1,237,000, and the improvement of production, handling, and assembly time in this research is 51.7%, 33.3%, and 52.7%. After testing on water that has passed the filtration process, namely TDS, it shows the TDS level was 95 ppm, previously at 142 ppm. This research helps the user to make a specific decision for design options and identify the design efficiency that indicates some future events in the redesigning process of the water filter. Moreover, the DFMA method for analyzing and redesigning an outside tool has never been used in previous research. In terms of future research, it is recommended to use another method to redesign outdoor tools, and it is suggested to combine the part and then change it to another.

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